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Affective Dimensions in Chemistry Education

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Preface

The inspiration for this book was the organization of a symposium entitled *Affective Dimensions in Chemistry Education* for the 2012 Biennial Conference on Chemical Education held at The Pennsylvania State University. The main purpose of that symposium—and of this volume—was to gather the most up-to-date expertise and research about the influence of the affective domain on learning in chemistry into one location. We hope that this book will serve as a resource for those wishing to address the affective domain as they research and solve problems in chemistry education.

About half a century ago, Bloom et al. (1956, 1964) published two handbooks outlining a taxonomy of educational objectives. In their conceptualization—which is not specific to chemistry education, but relates to education in general—educational objectives could be categorized into three major domains: cognitive, affective, and psychomotor. Of these three, the cognitive domain has received significantly more attention by researchers over the years, especially in the context of chemistry learning. With this volume, we intended to gather information about the influence of the affective domain on chemistry learning in order to inspire consideration of the affective domain both in the context of chemistry teaching and in the context of future chemistry education research.

Affective dimensions refer to such psychological constructs as attitudes, values, beliefs, opinions, emotions, interests, motivation, and a degree of acceptance or rejection (Koballa, 2013; Krathwohl, Bloom, & Masia, 1964). For several reasons, these dimensions have often been ignored or minimized in science education research literature, in curriculum development, and in assessment. First, it is challenging to measure affective constructs—such as students' motivation to learn science, their attitudes about learning science, and the degree to which they value scientific knowledge and practices—as these are hard to observe. Additionally, in practice, if a teacher explicitly states specific affective objectives in the classroom, some students will do everything they can to reflect those objectives, as they know that they will get credit for those valued behaviors. In such a case, students' demonstrated behaviors might not reveal their true attitudes and beliefs toward learning science. Second, many practicing scientists attempt to divorce the affective domain—subjectivity and individuals' feelings—from the cognitive domain, which is believed (by the scientists) to be more reason driven and objective. As a consequence, science is often presented in classrooms as being objective and separate from attitudes, values, beliefs, opinions, and emotions. Finally, because it is perceived to be more challenging to measure outcomes in the affective domain than in the cognitive domain, our current educational systems around the world tend to focus assessments on cognitive, instead of affective, objectives.

The Status Quo

So, what is the *status quo*? How is the current emphasis on cognitive objectives and the lack of emphasis on affective objectives influencing student interest in and retention in science fields? The drawbacks of our current educational practices were clearly observed in recent international studies like PISA (Programme for International Student Assessment) and described in a European Union document known as the "Rocard Report" (Rocard et al., 2007). According to this report, the following issues were highlighted:

- The number of young people entering universities is increasing, but they are choosing to study fields other than science; in consequence, the proportion of young people studying science is *decreasing (e.g., In 2003, the total physical science graduates in the USA dropped by 12 % (about 88,000) in comparison to 1995 (about 100,000); the same comparison for Germany is even more dramatic—50,000 vs. 101,000—a 50 % loss).*
- When looked at from a gender perspective, the problem is even worse as, in general, females are *less* interested in science education than males (e.g., females comprised only 31.2 % of the MST [mathematics, science, and technology] graduates in EU27 countries and *only* 31.1 % of MST graduates in the USA in 2005).

The current situation urges us to reconsider our current approaches to science education in general and to chemistry education in particular. Because positive affective dimensions have been shown to correlate with students' persistence and performance in science topics, a focus on affective dimensions is an important part of the solution to the global issues of lack of interest and retention in science education in general (and chemistry education in specific).

The Focus

This book focuses on affective dimensions and their influence on chemistry learning from two different perspectives: Part I reviews the theory related to the influence of affective domains on chemistry learning, while Part II is dedicated to the connection between research about affective dimensions and the practice of teaching and learning chemistry. We believe that all perspectives—theory, research, and practice—should inform the design of future studies about the affective dimensions of chemistry learning and, with this book, we attempt to provide one easy-to-access volume that will provide a foundation for those future studies.

Part I—"Theoretical Considerations"—highlights the following themes:

- Taber examines constructivist ideas about learning and how they might influence educational objectives in the affective domain.
- Rahayu reviews different methods for evaluating affective dimensions in the context of chemistry education.
- Menthe and Parchmann review influential theories of motivation and interest development to support the argument that emotional and affective aspects are crucial for attitudes toward and learning of chemistry in schools. Context-based learning approaches such as the German project *Chemie im Kontext* are reflected from the perspective of their ability to foster students' interest and motivation.
- A. Kahveci focuses on research findings from the literature over a period of several decades regarding the impact of gender on student affect related with chemistry. Student affect is portrayed in tandem with the relationship between affective variables and achievement, followed by the discussion of the gender effect.
- Dittmer and Gebhard highlight the significance of intuitive beliefs concerning socio-scientific issues and suggest that teaching about scientific issues in chemistry education should be done in an unbiased manner.

The following contributions around the globe enriched Part II of this volume, "Research and Practice":

- Abels focuses on students with cognitive and emotional/behavior disorders. She illustrates a case study using the approach of emancipatory action research to investigate how "inquiry-based science education" can successfully be implemented in an inter-year special needs class (5th and 6th graders).
- Taber reports his research findings on meeting the needs of gifted learners. A major problem in the education of gifted learners is lack of challenge, which is needed to ensure such students are able to make progress. Lack of challenge can also influence learner motivation and even lead to boredom. Meeting the needs of gifted learners is therefore a matter of matching task demand to their abilities to meet their emotional as well as their cognitive needs.
- Fechner et al. focus on the evaluation of affective variables in context-based learning (CBL) environments. On the basis of prior research designs and instruments, they argue that attitude has to be perceived as a multifaceted construct. Different research designs and attitude instruments are discussed and related to the theoretical background of motivation and interest.
- Xu et al. argue that instruments in the affective domain may not be equivalent when tests are administered to populations with different sociocultural

influences. They provide evidence from a study in which the same instrument of attitude toward chemistry was used to gather data from students in different sociocultural environments to support their claim.
- Cheung provides an extensive review of the literature on chemistry self-efficacy, reports recent research studies about self-efficacy conducted in Hong Kong secondary schools, and offers some directions for future research on chemistry self-efficacy.
- Yoon et al. report their research on a problem-based learning (PBL) chemistry laboratory course in order to elucidate differences in the influence of the course on students' scientific attitudes, as well as their creative thinking abilities and self-regulated learning skills.
- Liu and Huang introduce the concept of affection and categorize the affective dimensions in chemistry education. They also discuss the potential application of cognitive neuroscience methods—such as electroencephalograms (EEGs), event-related potentials (ERPs), and functional magnetic resonance imaging (fMRI)—to chemistry education research about the affective dimensions.
- Markic and Eilks discuss the use of drawings of classroom situations for exploring, researching, and assessing the pedagogical attitudes of chemistry teachers and teacher trainees.
- Markic examines the attitudes and perceptions that chemistry teachers hold when it comes to dealing with linguistic heterogeneity in the classroom.
- M. Kahveci reports a study examining chemistry majors' attitudes toward learning physical chemistry from a gender perspective.

Peer Review

Manuscripts were evaluated by the editors to determine if they matched the scope of the book and then sent for a full cycle of review by two peers. We gratefully acknowledge the essential contributions of these reviewers, as their rigorous attention to detail and to scholarship has improved the quality of this volume.

1. Simone Abels, University of Vienna
2. Sevil Akaygun, Bosphorus University
3. Michelle Dean, Kennesaw State University
4. Ayla Cetin Dindar, Middle East Technical University
5. Arne Dittmer, University of Regensburg
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Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walberg-Henriksson, H., & Hemmo, V. (2007). *Science Education NOW: A renewed pedagogy for the future of Europe* (European Commission.). Luxembourg: European Commission.

Contents

Part I
Theoretical Considerations

Meeting Educational Objectives in the Affective and Cognitive Domains: Personal and Social Constructivist Perspectives on Enjoyment, Motivation and Learning Chemistry

Keith S. Taber

Abstract Constructivist ideas about learning have been highly influential in science education over several decades. Debate continues between some educational scholars about the value of constructivism as the basis for informing effective instruction. However, in teaching the sciences, some core constructivist ideas have largely been accepted and indeed commonly even become taken for granted. Most commonly, constructivist accounts focus on learning, either as an individual act of knowledge construction or as participation within a community of practice, and have tended to relate to issues of knowledge and/or authenticity that reflect a cognitive focus. This chapter revisits constructivist ideas about learning to ask what they can offer when considering educational objectives in the affective domain. It is argued that guidance that largely derives from cognitive perspectives on learning often also makes good sense when our focus is on affect. It is suggested that the traditional emphasis of research within the constructivist research programme on *what* is learnt should be supplemented by a simultaneous consideration of how learning activities are experienced by the students.

1 Introduction

Within the broader educational community, constructivism is understood in diverse ways and has been the subject of quite intense debate (Phillips, 2000). Constructivist approaches to teaching have sometimes been seen as equivalent to 'progressive' or 'reform' education or synonymous with discovery learning or teaching by enquiry. Some association with such terms is certainly justified, but unfortunately, given such diversity in use, 'constructivism' has become a rather vague term that

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specifies little when used without further qualification. So, a high-profile debate based in the United States considering the merits of what has been labelled as constructivist instruction (Tobias & Duffy, 2009) was significantly undermined because some of those claiming to criticise what they consider constructivist teaching characterised it in terms of setting learning activities with *minimal* guidance from teachers, such that learners were expected to largely discover canonical knowledge for themselves (Taber, 2010a). Yet, it was that kind of naive teaching for discovery learning that Rosalind Driver (1983) long ago argued was inconsistent with constructivist thinking. Teaching which is genuinely informed by constructivist ideas about learning does not minimise teacher input but rather seeks an *optimal* level of guidance that can best 'scaffold' student learning in the light of the natural mechanisms that make learning a constructive activity (Taber, 2011). It is argued below that optimal scaffolding is also important for the student's subjective experience of learning.

A naive notion of discovery learning sees science as unproblematically investigating nature, when it is now recognised that the epistemology of science is far from straightforward (Chalmers, 1982; Losee, 1993), and that science education needs to carefully guide learners towards the models and theories that are canonical knowledge, and which are often the outcome of many years of empirical and theoretical work by professional scientists interacting in a community of practice. Constructivism as a learning theory suggests learners will construct their own personal sense of their experiences (von Glasersfeld, 1989): constructivism as a perspective informing teaching seeks to help teachers guide the processes of learners' constructing knowledge so that it matches accepted scientific understandings. Teaching that is genuinely informed by constructivism as an education theory (Taber, 2011) is certainly *not* about minimal guidance. However, there are good reasons to believe that it is important that learners are not given excessive guidance but rather are required to—as far as possible—develop arguments and recognise key links for themselves. This argument is normally made in terms of the importance of developing the learners' cognitive skills, but here, it will be suggested it is just as important to consider the student's subjective learning experience. From both the cognitive and affective perspective, teacher guidance should be optimised: to structure and support desired learning, without reducing the learner to a passive consumer of instruction.

1.1 Constructivism in Science Education

Within science education, constructivism has become somewhat more clearly defined than in education more widely, having been introduced into the field by a range of scholars (Driver & Easley, 1978; Driver & Erickson, 1983; Gilbert & Watts, 1983; von Glasersfeld, 1989) who have drawn upon key constructivist thinkers (Ausubel, 1968; Kelly, 1963; Piaget, 1929/1973; Vygotsky, 1934/1986). There are still many 'flavours' to constructivist thinking reflected in science education (Bickhard, 1998; Bodner, Klobuchar, & Geelan, 2001; Grandy, 1998), but there is sufficient consensus on the core ideas for constructivism to have become very widely accepted as a basis for teaching (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Fensham, 2004; Matthews, 1998; Tobin, 1993; Yager, 1995) and also as the starting point for a major research programme (Taber, 2006, 2009).

Constructivism has its critics, even from within science education (Matthews, 1993, 1994; Scerri, 2003), but such criticisms tend to be aimed at the philosophical underpinnings of some constructivist presentations, whereas the core of constructivism *as applied* in science classrooms is built upon findings from research into human learning. That is, at its heart, constructivism in science education has drawn upon work in the psychology of learning, not on philosophical debates about epistemology.

There are many existing accounts of constructivism in education, in science education more specifically (e.g. Taber, 2009) and indeed in chemistry education in particular (Bodner, 1986; Coll & Taylor, 2001; Taber, 2000, 2001, 2010b). Such accounts have tended to be primarily concerned with cognition: with considering how teaching should take into account the cognitive processes by which learning occurs (Taber, 2013b). Indeed, constructivist thinking in science education has drawn upon findings from cognitive and information science (Osborne & Wittrock, 1983, 1985). Those constructivist perspectives that can be labelled as 'personal' constructivism tend to be focused on the idea that knowledge is represented in the individual's mind and so tend to be concerned with how such representations have been acquired and developed. Other, 'social' constructivist, approaches tend to focus more on how learning is mediated by social interaction, for example, through participation in the authentic practice of a community. In both cases, the key concerns tend to be the development of knowledge, skills or competence in practice. The present account seeks to consider the extent to which the discourses of personal and social constructivism can encompass the affective as well as the cognitive domains.

2 The Affective Domain

The educational psychologist Benjamin Bloom (1968) is well known for 'his' taxonomy of educational objectives in the cognitive domain. Bloom and his colleagues identified six classes of educational objectives that were seen as forming a kind of hierarchy relating to the cognitive demands of different tasks. The gist of this work has been widely adopted in educational practice: so, for example, applying an idea is considered more demanding (a higher level skill) than simply recalling, or demonstrating comprehension of, it. Bloom's original project, however, was also to encompass the affective and sensorimotor domains, as well as the cognitive domain. Bloom highlighted how the 'the objectives of education increasingly stress interests, attitudes, and values in the affective domain' (Bloom, 1972:

341). However, the term 'Bloom's taxonomy' has entered educational discourse in relation to the work on the cognitive domain, whilst the companion work on the affective domain (Krathwohl, Bloom, & Masia, 1968) is generally less well known or cited.

We might suspect that, in part, educators were less receptive to consider educational objectives in the affective domain when Bloom and colleagues' work was first published. However, it is also possible that the taxonomy on the affective domain was considered less useful or applicable for other reasons. Its authors acknowledge both (1) that at the lowest levels of the taxonomy, it is difficult to distinguish affective from cognitive factors and (2) that in places, the arrangement of discrete categories within the affective domain typology into a hierarchy was somewhat arbitrary.

It is especially relevant in the context of the present chapter to acknowledge, as Bloom and colleagues realised, that it is difficult to think about the affective domain in isolation from the cognitive. There is an obvious parallel, for example, between the ideal of a consistent system of values (considered to be attained at the highest level of the affective domain) and of a coherent conceptual framework, as both rely upon the integrative function of human cognition (Wiltgen, Brown, Talton, & Silva, 2004). If the taxonomy for the affective domain is seen as reflecting the development of a coherent value system, then it seems strongly related to ethical and moral development (Kohlberg & Hersh, 1977), which are closely linked with other aspects of intellectual development (Perry, 1970). It is also possible to suggest a tentative link between the higher levels of the typology of educational objectives in the affective domain and the later version of Maslow's hierarchy of needs (Maslow, 1943) which posited a stage of transcendental 'peak experiences' as a source of human motivation (Koltko-Rivera, 2006; Maslow, 1970) beyond the need for self-actualisation—i.e. 'being highly engaged in what one does and having a sense of meaning and purpose in one's life' (Peterson and Park 2010: 322). Whilst this extension to Maslow's theory has perhaps not received the attention it might have deserved (Koltko-Rivera, 2006), the notion that people may experience a state called 'flow' (Csikszentmihalyi, 1997) when they engage in highly motivating activities has become widely discussed.

2.1 Learners in Flow

It has been suggested that student learning experience can be characterised in terms of how task demand matches student skill level (Nakamura, 1988). Trivial tasks lead to apathy: the tasks may get completed at some level, but without any care. However, if students are set high-demand tasks, for which they lack the requisite skills, then they get frustrated and experience anxiety (see Fig. 1). Conversely, if students with high skill levels are set tasks that make very limited demands on those skills, they are likely to be bored. However, when a task makes high demands that are matched by high levels of skill, students can potentially engage productively,

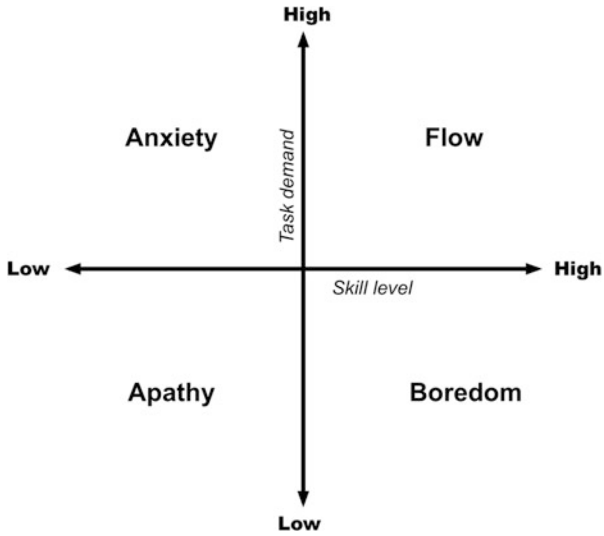

Fig. 1 Learners are said to be able to experience ‘flow’ when they are set demanding learning activities and have sufficient skills to be successful in meeting the demands

and—when the match is optimal—they experience what has been termed ‘flow’ (Csikszentmihalyi, 1997) which can occur when there is a high level of engagement in an activity. In simplistic terms, this experience may be indicated when students are disappointed when the end of the lesson arrives and cannot believe how quickly the time has passed.

There are two important points to note about this model. Firstly, ‘high’ and ‘low’ are relative terms, and not absolutes. Secondly, whilst applying high levels of skills to a demanding task can lead to a positive learning experience, this is not necessarily going to be so. The learner has to feel the activity is worthwhile: there is limited satisfaction in being able to do a difficult task well if it seems pointless.

Motivation is clearly an important consideration here. There are various theories of motivation drawn upon in education (Kusurkar, Ten Cate, van Asperen, & Croiset, 2011). However, it is common to distinguish intrinsic motivation, where a person values an activity for its own sake (because it is enjoyed and related to personal goals, e.g. because it is considered to support career goals), from extrinsic motivation, where an activity is undertaken, for example, to avoid negatively perceived external sanctions (Lavigne & Vallerand, 2010). In part, motivation may depend upon initial interest in a topic, but there is clearly also potential for considerable feedback effects due to a learner’s subjective experience of learning activities—the extent to which they offer a sense of challenge and whether the learner considers he or she has been successful in meeting that challenge (see Fig. 2).

Earlier in the chapter, it was suggested that constructivist teachers should seek to offer an *optimal* level of guidance to learners, which can be understood as making the task demand high enough to offer challenge, without becoming so difficult that the learner perceives the chances of success as low and becomes demotivated. That matches the set of conditions in which flow is said to be possible. In the remainder

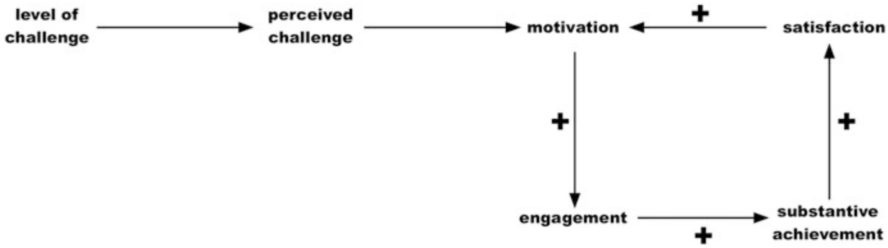

Fig. 2 Success in meeting challenges can motivate further engagement in learning. The *plus* signs indicate the potential for feedback effects, as a change (increase or decrease) in one factor is likely to lead to the same direction of change in the next

of the chapter, some key ideas from constructivist thinking will be considered with a view to considering how they might contribute to a *positive* learning experience from the subjective perspective of the learner, as well as an *effective* one from the external perspective of the teacher.

3 What Does Constructivism Suggest?

Although there are many different accounts of constructivism, the notion of constructivism that has been widely taken up in science education is essentially a form of learning theory. The message of seminal papers (Driver & Easley, 1978; Driver & Erickson, 1983; Gilbert, Osborne, & Fensham, 1982; Gilbert & Watts, 1983; Osborne & Wittrock, 1983) has been formulated as a number of hard-core programmatic commitments (Taber, 2006, 2009). Among these, and especially relevant here, are:

- Learning science is an active process of constructing personal knowledge.
- Learners come to science learning with existing ideas about many natural phenomena.
- Learners' conceptual structures exhibit both commonalities and idiosyncratic features.
- The learner's existing ideas have consequences for the learning of science.

The emphasis represented in this set of propositions can be characterised as a *personal constructivist* theoretical perspective with its focus on the individual and in particular on the representation of knowledge in the individual's brain. Some commentators would criticise this focus as too limited, pointing out that the individual operates in, and is strongly influenced by, a cultural and social context (which is certainly the case) and—more contentiously—that it is inappropriate to see learning as a process that happens to, and knowledge as something that can be located in, individuals (Collins, 2010).

Social (cf. personal) constructivism has a somewhat different focus (Leach & Scott, 2002; Smardon, 2009) but is not necessarily seen as being at odds with personal constructivism. Where some social constructivists/constructionists may see learning and knowledge as inherently communal activities (Strong & Hutchins, 2009), many others who adopt social constructivist perspectives (and sadly, these terms are used in a range of ways by different authors) build on the Vygotskian tradition (Scott, 1998) where *individuals* are supported in obtaining higher cognitive functions through cultural tools—such as language and other symbol systems—and interaction with others who are already enculturated (Vygotsky, 1978). So, for example, a 'normally' developing human can learn to understand and use syllogism but is unlikely to acquire that particular thinking tool unless brought up in a culture where that formal logical tool is represented in discourse such that the individual is exposed to its use and gets to practise it with others who have already acquired it as part of their normal discourse practices (Luria, 1976). Social constructivists might say that we have to first experience syllogism on the social plane before we can internalise it and make it a personal resource for cognition. One might suggest:

1. Syllogism is a logical tool used in certain discourse communities.
2. Learning of abstract forms of knowledge depends upon cultural mediation.
3. Therefore, syllogism will normally only be adopted as a thinking tool by those brought up in discourse communities that regularly employ syllogism.

Social constructivists often see science education as about induction into a community, as engagement in (more or less authentic) practices and—at the higher levels (e.g. research training)—as moving from peripheral to central legitimate participation in cultural practices (Lave & Wenger, 1991). From such a perspective, learning science becomes a form of cognitive apprenticeship (Hennessy, 1993; Kuhn, 1996), and authentic school science is better framed in terms of participation in appropriate discourse practices rather than being seen as about learning content. One recent trend which might be seen to reflect the influence of social constructivist perspectives is the growing interest in the role of argumentation in school science (Erduran, Simon, & Osborne, 2004). This work has often drawn upon the ideas of philosopher Stephen Toulmin (2003/1958), and has been developed in various contexts, including chemistry learning (Cole et al., 2012).

4 Applying Principles from Constructivism with Due Concern for the Affective Domain

The argument made in this chapter is that although (1) constructivist principles are commonly understood in terms of *the logic* of how students can come to develop personal knowledge and/or to take ownership and mastery of the shared practices of a discourse community (i.e. the focus is often on how constructivist ideas inform teaching by paying attention to *the cognitive* processes involved in learning); (2) it makes sense to also see constructivism in terms of paying attention to the learner's subjective experiences of the learning process as these are linked to such issues as engagement (degree of involvement in activities), motivation (drivers for being involved), academic self-concept (see below), interest (desire to find out more about), etc. (Ainley, 2006; Silvia, 2008).

Ausubel famously wrote that 'the most important single factor influencing learning is what the learner already knows' (Ausubel, 1968: vi), and constructivism puts a great emphasis of eliciting what a learner already knows, in order to inform teaching. The argument here is that constructivist thinking should also lead us to emphasise the elicitation of *how the learner feels* about learning experiences. So, for example, it has been claimed that chemistry learners' academic self-concept—their perception of themselves as a chemistry learner—influences their course performance, even when controlling for objective measures of ability (Lewis, Shaw, Heitz, & Webster, 2009). That is, a student who is capable in chemistry, but feels they are not a strong chemistry student, will generally perform less well than an equally capable student who has a more positive self-concept regarding themselves as a chemistry learner.

A number of principles can be drawn from both personal and social constructivist perspectives that relate not only to the effectiveness of teaching in terms of the conceptual learning achieved (the usual focus of constructivist studies) but also in terms of *the learners' experience* of studying the subject. In the account below, the device of the constructivist chemistry teacher is used to stand for the teacher who looks to inform their teaching by drawing upon the constructivist perspective on teaching and learning (Taber, 2011). This is not to suggest that real teachers can simply be considered as constructivist or otherwise—rather than different flavours of constructivist, or constructivist to some degree, or constructivist in some situations, etc. For example, when Bektas observed a sample of classes in English secondary schools and a sixth form college using an observation schedule based on indicators of teaching that might be considered informed by constructivist learning theory, he found that much of the teaching observed had elements of both what might be considered constructivist teaching and more traditional 'didactic' teaching (Bektas & Taber, 2009). The constructivist teacher referred to here is then an ideal, a kind of normative model that real teachers will reflect (and aspire to) to differing extents.

4.1 Learning Is a Process of Personal Sense Making

Core to the personal constructivist perspective on learning is the idea that meaningful learning is about *making sense:* reflecting Ausubel's (2000) focus on 'meaningful' learning. Most chemistry teachers would very much support the idea that they want learners to understand material so that it makes sense to them. However, understanding is usually primarily linked to evaluating learning in terms of the cognitive domain: so regardless of whether a student *feels* they have a good understanding of an idea, a teacher judges functional understanding in terms of whether the learner can apply the ideas appropriately in the formal assessment situation. Whilst this can be considered to reflect a behaviourist perspective (Watson, 1967), it often seems the appropriate way to work in educational contexts dominated by high-stakes formal testing of students. Learners will often be complicit in this, asking only to be told what is needed to pass the test or exam. Motivation here often seems to rely upon external indicators, rather than being based on the epistemic 'hunger' to know and understand (Maslow, 1943). Yet, whilst this gives students confidence to feel they can succeed in formal tests, it hardly encourages enthusiasm for a subject. Lynch and Trujillo (2011) reported from a study of undergraduate students studying organic chemistry in a US university context that 'intrinsic goal orientation was positively associated with academic performance, while extrinsic goal orientation was negatively associated' and suggested that it could be 'difficult to sustain productive academic behavior if one is mainly concerned with grades, especially as the material becomes progressively more difficult over the year' (p. 1359). The argument here is that it should not be enough for a constructivist teacher that learners show a functional level of understanding in terms of being able to tackle typical test questions, but rather, they should also *feel* they have a good understanding of material.

Constructivist research has highlighted the alternative conceptions that students often hold for scientific topics, and it needs to be recognised that although student perceptions of learning making sense is important, students with well-developed alternative conceptions may well feel they understand material, without that understanding being consistent with the canonical knowledge of the subject (Taber, 2013b). The constructivist teacher is aiming for *both* an understanding that matches well to target knowledge set out in the curriculum *and* for students to feel that material makes sense to them. This consideration is now informing some research into students' understanding of chemistry and other science topics—an area previously dominated by cognitive concerns: what conceptions students hold—where in addition to being asked to answer conceptual questions, students are asked to rate their confidence in their responses. One example is a diagnostic instrument developed to explore how students taking organic chemistry courses understand the concept of acid strength (McClary & Bretz, 2012).

Generally, then, this means that the constructivist teacher should only look to move on after presenting an idea *both* if (1) students' comments, spontaneous questions and responses to teacher questions suggest they have understood the idea and (2) if—*on being asked*—they report feeling comfortable that the idea makes sense to them. It follows that this kind of constructivist teacher will regularly invite students to report their subjective experiences of learning, *as well as* check for objective evidence of canonical understanding.

Now, there are potential complications here—some ideas in chemistry may be very abstract and not be readily taught in short lesson segments in a way that students feel they 'get them'. Some core concepts (such as 'element') may be in this category, where a deep understanding is only possible after meeting and using the ideas in a range of contexts. In these situations, it seems unlikely that students will feel they can make good sense of the ideas when they are first introduced. Here, the constructivist teacher needs to be explicit about how this is a common problem and how students will have to be patient—perhaps over some considerable period—before they really feel the ideas do make good sense to them. In effect, the teacher is asking for the students to reserve judgement on the sensibility of a concept and to trust the teacher that this will be resolved over time. Not surprisingly, student-teacher relationships that are considered to be of high quality have been associated with students' levels of intrinsic motivation to learn (Haidet & Stein, 2006), and in this situation, effective teaching clearly requires a strong positive *relationship* between teacher and student such that the student will have confidence and trust in their teacher, rather than become frustrated and perhaps disengaged in the subject.

Students are more likely to be prepared to offer such trust if the teacher is open about the issue, so it is acknowledged that the feeling of things not quite making sense is common in this topic, and if the teacher has demonstrated previously that she or he is genuinely concerned that students feel they understand the material—and regularly teaches in a way that makes it an imperative that students consider what they are learning makes sense. Therefore, it is not sensible to start teaching a new class by teaching a concept that it seems likely many students will struggle to come to terms with, even if the structure of the subject might suggest it is logically a good starting point for a course. That said, the constructivist teacher will do what she or he can to support developing understanding with appropriate simplifications, models, analogies, metaphors, etc., where these offer learners an opportunity to feel they are starting to understand the challenging abstract ideas that are not immediately directly accessible (this is discussed further below).

4.2 Learning Is an Iterative Process Where Learners Interpret Experience (Including Teaching) in Terms of Existing Conceptual Frameworks

A fundamental premise of the personal constructivist perspective is that the individual builds up their understanding of the world in an iterative manner. At least since the widely reported work of Piaget (1970/1972), it has been generally accepted that the human brain has evolved to model—and so *make* sense of—experience and that the young child develops relatively primitive 'concrete' conceptual notions that can then act as the foundations for developing more abstract ideas (Vygotsky, 1934/1994). It has even been argued that *all* our abstract concepts are metaphorical in the sense of necessarily being built ultimately upon internal mental representations of directly perceivable features of the world (Lakoff & Johnson, 1980).

In effect, a learner in a chemistry class draws upon existing conceptions and conceptual frameworks as the tools to make sense of learning: their existing understanding of the world provides the interpretative resources for further sense making. So meaningful learning can only occur when the learner can recognise how what is being taught links with their existing knowledge (Ausubel, 2000), as only *then* can they make sense of teaching. That is, teaching not only has to offer potential links with prior understanding, but those links have to be obvious to the learner. Our constructivist teacher therefore will not only plan lessons in accord with their expectations of learners' prior knowledge and understanding but will be constantly testing out how teaching is being received to check that students are 'getting it'.

Again, this aspect may have two distinct features. One relates to the structure of the subject matter—the constructivist teacher certainly analyses the content to be taught from a logical perspective to identify which concepts are needed as prerequisite knowledge for others, and so to offer a logical teaching (and so learning) order (Herron, Cantu, Ward, & Srinivasan, 1977), but also considers students' interests, hobbies and activities outside the chemistry class, to see how these might support teaching.

In part, this could be looking for applications that might catch a learner's imagination, but it can also be a consideration of analogies and metaphors that might be especially salient. Teaching is about making the unfamiliar familiar, and one way of doing this is to relate the unknown that is to be learnt to a known that is familiar and is in some sense similar (Taber, 2002). The argument is that, for example, using a sporting analogy with learners keen on sports can make the material to be taught seem less abstract, and so potentially less threatening, and more memorable because engagement is increased by talking about students' own interests. Of course to be effective, the sporting analogy has to reflect a genuine structural mapping from the familiar sporting analogue to the target chemical concept area being introduced, as well as linking to an area of student interest.

For example, a common ploy used in chemistry teaching is to make the molecular realm seem familiar by discussing molecules, ions, atoms and electrons in terms of a social narrative. As part of normal development, we acquire a 'theory of mind' (Whitebread & Pino-Pasternak, 2010) that allows us to understand the actions of other people in terms of their desires, intentions, feelings, etc. Young children commonly overgeneralise this to inanimate objects (such as clouds) and in particular all kinds of animals, and in chemistry, it is common to talk as though chemical 'behaviour' (sic) is the deliberate action of atoms and molecules to achieve desirable goals. In particular, atoms are often said to need or want full electron shells or octets of electrons, and this is the basis of a very common alternative conceptual framework in chemistry (Taber, 1998, 2013a).

In this case, the use of anthropomorphic language is very effective at helping learners make sense of chemical ideas and offering them ways of thinking that they often feel they understand and so tend to readily retain. Yet, these ways of thinking are chemically dubious and tend to impede the development of more canonical ideas. This may be a useful reminder that whilst it is generally desirable that learners find teaching sensible and that teachers make abstract ideas seem familiar and unthreatening, sometimes teaching that leads to canonical knowledge that is highly abstract or counter-intuitive may need to be—initially at least—less comfortable for learners (and thus the importance of rapport and trust in the student-teacher relationship, as suggested above). The notion of academic self-concept has been used to characterise how students describe and evaluate themselves as academic learners and is considered to have a reciprocal relationship with academic achievement (Marsh & Martin, 2011). That is, just as high achievement is likely to lead to a student holding a positive academic self-concept, actually having a positive academic self-concept can influence achievement. A positive self-concept about oneself as a chemistry student is likely to be especially important when learning material that cannot be immediately seen to 'make sense'. This is important, as learning of complex and abstract material is not a quick process, but may rather take place over extended periods such as weeks and months.

4.3 Learning as a Slow Process: (1) The Bottleneck in the System

Research into cognition suggests that the conscious processing of information is highly dependent upon a component of our mental apparatus referred to as 'working memory' (Baddeley, 2003). There is much evidence that a good deal of our cognitive processing (including much we would sensibly class as thinking) occurs pre-consciously (Taber, 2013b)—however, working memory is 'where' we do our conscious thinking, planning and problem-solving. Yet, working memory has been shown to have very modest capacity, such that we can only mentipulate a very limited amount of novel information at any one time. This has implications both for planning effective teaching and for how learners experience learning of complex material. Teaching that presents new concepts and information at too great a rate is unlikely to lead to effective learning as it will overload working memory (Jong, 2010). This is not only inefficient but is likely to be demotivating, as the learner will usually be aware that they are not effectively juggling all the new information and so is likely to feel stressed by the mismatch between learning demands and apparent learning capacity.

The constructivist teacher needs therefore to ensure that the pace of meeting novel material matches what learners can effectively process. However, this is not easy to judge because the perceived complexity of information presented is subjective in the sense that it depends upon how an individual is able to conceptualise it in terms of existing conceptual frameworks. Our cognitive systems spontaneously 'chunk' information to more efficiently use working memory (Mathy & Feldman, 2012), but this generally relies upon recognising *familiar* patterns in information perceived. Teachers, as subject experts, may underestimate the complexity of what is being presented as perceived by a student who is a relative novice. For example, equations representing common chemical reactions may actually be perceived by novices as complex strings (Taber & Bricheno, 2009).

Also, a system that looks very complicated to one learner might spontaneously trigger an analogy with something familiar to another learner, such that it is more readily related to, and so accommodated within, existing mental structures. Here, individual differences become very important. When asked to generate their own analogies for scientific concepts, learners may offer quite idiosyncratic examples reflecting strong individual differences in learners' knowledge structures. Learners have suggested that a chemical reaction is like hell; an ionic bond is like love; and that a molecule is like the Bible, or alternatively like Africa (Taber, 2012)!

This creates a complication when formal scientific concepts are tested in novel contexts, for example. Questions that are intended to require learners to apply learnt ideas in unfamiliar situations test application rather than simply recall but may present very different demands to different learners (Taber, 2003): for those who are very familiar with the context, the application may already be well known and understood (and so the task reduces to recall), whereas any learners who may lack the expected background knowledge about the question context could be obstructed from demonstrating their understanding of the scientific concepts. Something similar was found with early IQ test items that expected those tested to hold relevant cultural background knowledge—such as knowing about a baseball diamond—and which consequently discriminated against those from minority cultural backgrounds (Gould, 1992). This leads, again, to the conclusion that the constructivist teacher needs to be constantly monitoring how (individual) learners are responding to teaching and how they perceive the pace of a presentation.

4.4 Learning as a Slow Process: (2) The Biology of Consolidation

Knowledge representations within the brain are organised as something like an extensive concept map. Like the concept maps we get students to draw (to reflect their organisation of knowledge), connections may be missing or suboptimal but can be added and refined over time. Research suggests that when new memories are first represented, they are initially linked to more established memories through a temporary mechanism. However, there are automatic processes in the brain that can supplement (and in time replace) these interim links with new more direct links that can allow ready and permanent shifting between the recent and established learning (Wiltgen et al., 2004). The extent to which this consolidation process occurs may depend upon the new learning being reinforced regularly whilst the temporary links are still operating. The neural processes that form the permanent linkage operate when there has been sufficient stimulation of the new knowledge representations and their temporary connections with more established learning.

Constructivist theory suggests that application of new learning makes significant demands on learners, but that over time, the same learning becomes robust such that it may act as the foundations for making sense of, and learning, subsequent teaching. At this point, it can be assumed, taken for granted and treated as a resource for supporting further learning. However, the research into memory consolidation also suggests that there is a significant period over which initially 'fragile' new learning needs careful reinforcement in class before it becomes 'robust' enough to be taken for granted in teaching, and this may typically be of the order of weeks or months. There seems to have been little, if any, substantive research on this issue in authentic science learning contexts to explore timescales in relation to particular learning and potential conditions that might accelerate consolidation. Again then, the constructivist teacher needs not only to be aware of the general principle here but also to be active in seeking feedback from individual learners to test out when new learning is sufficiently consolidated. Only then can it be chunked within working memory so that the learner can simultaneously coordinate it with new material presented in teaching.

4.5 Learning Is Mediated by a More Knowledgeable Other

The main contribution of the social constructivist perspective to constructivist ideas in education has been to emphasise how much learning is not based on a lone individual interacting with the physical environment but rather occurs in a social context. Indeed, school learning is not generally about developing spontaneous concepts based on direct experience of phenomena but rather learning what Vygotsky (1934/1994) called 'scientific' or 'academic' concepts, that is, acquiring acceptable versions of canonical pre-conceptualised knowledge considered to be in the public domain (Taber, 2013b). In effect, learning concepts 'second-hand', largely through verbal communication, short-cuts (or at least complements) the spontaneous processes of developing concepts from direct experience (Karmiloff-Smith, 1996). Such learning is socially mediated (to shape conceptual development in ways consistent with canonical knowledge), and of course, schools, colleges and universities can be considered to be primarily institutions for providing such mediation.

Vygotsky (1934a) highlighted the importance of learning in what he called the zone of proximal—or next—development (ZPD), which referred to the activity 'space' beyond what a learner could yet achieve unaided, but where they could achieve with suitable support, such as from a teacher or more advanced peer. This leads to the notion of 'scaffolding' learning, setting up challenges that are beyond the learner's zone of actual development but are within the ZPD when suitably structured and supported. Effective teaching provides learning activities that are challenging, but sufficiently scaffolded to be achievable, and then reduces the level of support as the individual's level of competence increases to the point where they become capable of achieving mastery of the task unaided.

Scaffolding can involve both helping the learner cue and organise the prerequisite knowledge that is most relevant to new learning ('Platforms for New Knowledge' or *PLANKs*), rather than assuming learners will recognise essential prerequisite learning and how it relates to new teaching, and providing them with structure ('Provided Outlines Lending Support', or *POLES*) when tackling challenging novel learning tasks (Taber, 2002). This is represented in Fig. 3.

As just one example, chemistry students may be asked to learn to undertake a series of titrations from which they can in principle calculate some unknown via various intermediate calculations. These exercises involve the coordination of a range of information, including reaction equations and various data about reagents used, and—when first met—such exercises may seem to some learners as totally

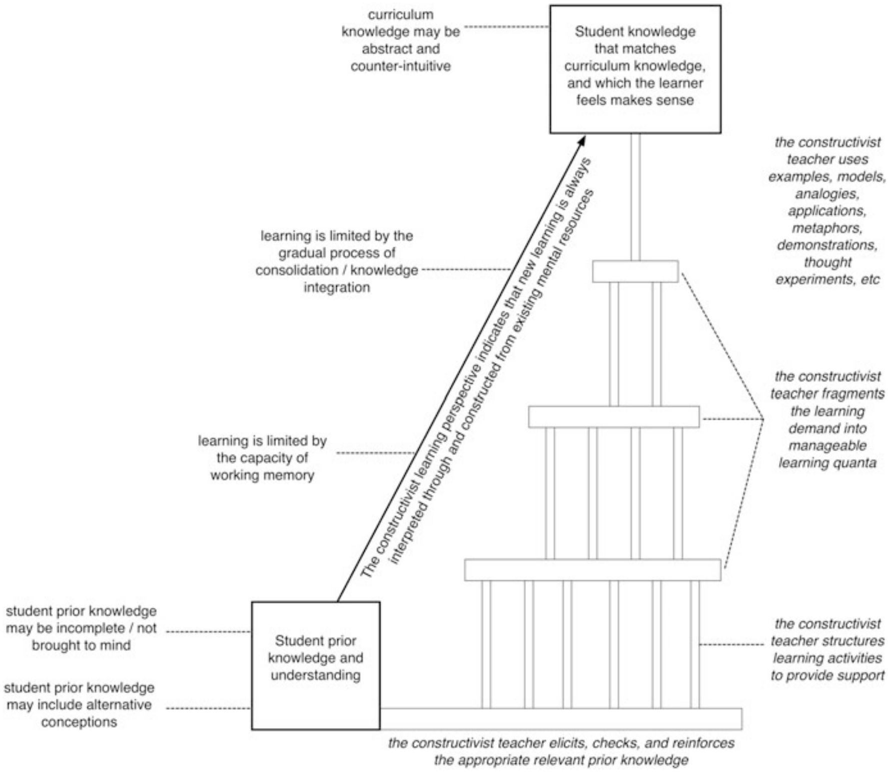

Fig. 3 Constructivist teaching involves scaffolding learning

overwhelming, even when the learner might be perfectly capable of each individual step in the process. The teacher can scaffold such activities by initially setting practical work that is pre-organised into small, clearly manageable steps, each of which is straightforward for students, highlighting which previously met concepts and skills are needed for that step and complementing this with classroom discussion of the logic of the overall process. Over time, students can be asked to undertake incrementally less structured versions of the activity, until they are able to handle the full procedure with minimal guidance. For most students, this transition will be partially about building up confidence, as well as about familiarisation with the type of activity and range of component steps, preparing them to be able to successfully complete the full process with limited teacher input.

4.6 Optimal Levels of Challenge

Judging the level of scaffolding initially needed, and the rate at which that scaffolding can be effectively faded, is critical to effective teaching. Oversimplifying a task (or fading scaffolding too slowly) makes it trivial and so it is not engaging or motivating to learners—potentially leading to boredom (see Fig. 1). Insufficient support (or scaffolding faded before students have made enough progress), however, may lead to failure and frustration (and so anxiety; cf. Fig. 1). When done well, scaffolding allows learners to not only make good progress but to readily recognise that they have mastered material that may have recently seemed too challenging. This can reinforce positive academic self-concept and associate the study of chemistry with positive feelings and successful learning experiences.

This suggests that a key feature of effective teaching is tuning the level of demand of tasks to match the learners. Learners do not only differ in terms of the skills and knowledge they have already mastered (their 'zone of actual development', or ZAD) but in the extent of their ZPD (Vygotsky, 1934/1986)—the activity space where they can achieve with suitable support (Taber, 2011). Whenever possible, learners should be working in their ZPD, where the demand of a learning activity presents a challenge that can be met with the scaffolding put in place by the teacher (see Fig. 4).

A student who is not being challenged and is working well with their capacity (within their ZAD) is not being facilitated to develop their thinking significantly, whilst a student facing demands they cannot respond to (beyond their ZPD or without the 'scaffolding' needed to support their learning) is unable to effectively learn from activities. This is not simply a matter of cognitive outcomes but also of the learner experience. When students feel they are being successful in responding to challenges in their learning, they are more likely to experience learning as a positive—rewarding, worthwhile—activity that makes them feel good about themselves (see Fig. 2). Similarly, there is potential for negative feedback if learners regularly experience failure in the face of such perceived challenges. Clearly, there are other factors in play, but the teacher's ability to fine-tune task demands so that learners recognise they are being asked to stretch themselves, but are ultimately successful, is often likely to be an important contribution to the student's subjective experience of classroom learning.

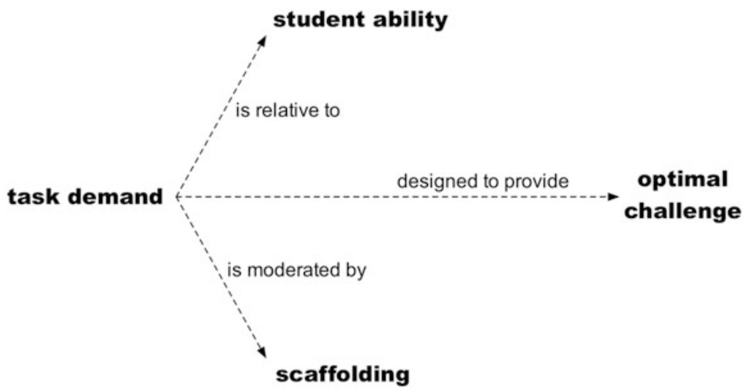

Fig. 4 The teacher seeks to offer optimal demand by matching the learning activity and support provided to the ability of the learner

4.7 Science Operates as a Community of Practice

Another key focus found in social constructivist work is the emphasis on the communal nature of science. From a cognitive perspective, an important idea is that of peer review: that claims in science are validated by being evaluated by other scientists, and therefore, argumentation becomes especially important as scientists have to make a case to support knowledge claims they present to the community. From this perspective, the authentic science classroom involves debate, with ideas being constantly exposed to testing through coordination with evidence.

This may be particularly challenging given work which suggests that school-age learners are more likely to prioritise (although not necessarily as a conscious choice) seeking consensus during discussion, rather than critical analysis of ideas (Solomon, 1983, 1992). The argument is that maintaining social cohesion is often the imperative that channels learners working in groups, rather than critical thinking. However, workers concerned with promoting dialogic classroom learning have developed approaches to shifting such patterns, through—for example—the adoption of student-agreed ground rules for discussion work, so that with practice, productive dialogue becomes possible (Kleine-Staarman & Mercer, 2010).

There may be a 'double-edged sword' in operation here. Most students (and of course, there are exceptions) put a high premium on appearing to be behaving in keeping with their social group and on being accepted and valued by the others in the group. Once students have learnt the ground rules of classroom discussion, then social pressure can help reinforce those rules if a student transgresses. Getting to that point may require some considerable work on behalf of the teacher. At university level, however, students may well have the skills and metacognitive understanding to effectively work in groups and to enjoy learning when the activities are well matched to their learning needs and level of development (Ryan, 2013). Moreover, competing within groups in a 'fun' context may be a strong situational motivator. For example, the authors of a paper describing how a board game was used in undergraduate chemistry classes to review work in groups reported both that 'student enjoyment of the game and their interest in using it as a study aid have been overwhelming' and that it acted as spur to informal peer tutoring within the groups (Mosher, Mosher, & Garoutte, 2012: 646).

Alternative conceptions that are already recognised as tenacious are likely to be reinforced when held by a group of learners who offer each other mutual support in terms of the reasonableness and social currency of their thinking. So, for example, in a study reporting on learning chemistry in a higher education setting, Liang and Gabel (2005: 1159) reported how 'it was found that students seemed easily satisfied with their non-scientific conceptions or ideas during the group discussion'. Similarly, people may be more easily persuaded of new ideas when those ideas appear to have been adopted by those around them (so individuals have been persuaded to agree with clearly incorrect statements—such as which of a number of lines is longest—simply through the presence of others who confidently maintain a falsehood is clearly the case). If professional scientists' judgements can be influenced by their social milieu (Kuhn, 1996), then how much more suggestible may young learners in school classrooms be?

Unfortunately, this is likely to mean students in science classes sometimes being persuaded by teaching because their friends seem to be, rather than because they have understood and been convinced by the logical case for what is being taught. We might say they are persuaded affectively but not cognitively. They may be genuinely committed to the new ideas, but not based upon the intellectual merits of those ideas.

It seems unlikely that such affectively motivated acceptance will lead directly to long-term conceptual change if it is not supported by cognitive grounds for conceptual change: yet, it may well be that such social factors could lead to a predisposition to consider and value the cognitive arguments for conceptual change, which may be a useful ‘lever’ that teachers can make use of when teaching challenging material. This then is an area where more research would be useful.

Earlier in the chapter, it was suggested that it may sometimes be necessary for learners to offer provisional acceptance of ideas that do not yet seem convincing, trusting their teacher when ideas initially do not seem to make sense to them: yet, solidarity with peers who may share alternative conceptions or have thinking dominated by the lifeworld attitude (Schutz & Luckmann, 1973) could act to impede acceptance of scientific ideas. It is a scientific value to be open to dispassionately exploring and considering new ideas, even when these seem counter-intuitive and competing with other ideas we currently find perfectly fit for purpose—yet, it may compete with a value to conform with the apparent belief systems of peer groups and of significant adults such as parents.

This analysis then suggests that social factors may complicate teaching for conceptual change through the different ways they can act as motivators. The influence of the social context on affective factors in learning is more nuanced and situated, varying case on case and even at different stages in the local classroom career of a particular group of students. This seems like an important focus for classroom research that takes into account not only the nature of a teacher’s teaching, and the cognitive factors influencing learning, but also how social networks complicate the motivational factors at work.

5 Conclusions

The space available here has only allowed a brief exploration of how constructivist ideas as they are commonly understood in science education relate to affective factors. Yet, two general observations can be offered.

Firstly, as might be expected, a social constructivist perspective offers a more complex view of learning than a personal constructivist view, such that it is seen that the same factors can work for or against intended learning depending upon nuances of the social context in which particular learning episodes are played out. Communal features of learning can reinforce learning impediments, or help facilitate progression in thinking, depending upon the specific circumstances. More research is needed to investigate how such learning contexts evolve over time and to identify key characteristics that can support teaching.

Secondly, and more unequivocally, much of what has been argued from the 'constructivist' programme in science education on grounds deriving from consideration of the cognitive domain would appear to also make sense from considering the affective domain. Indeed, the argument for a broadly constructivist perspective on teaching and learning is strengthened.

5.1 Implications for Teaching

Teachers should not only be diagnosing students' prior knowledge and seeking opportunities to link new teaching to their existing thinking, but teachers should also be looking for opportunities to actively co-opt learners into the process of constructivist learning. Finding out how learners experience teaching—when they feel things make sense to them; when they understand links with prior learning; when they feel they can cope with, or are overwhelmed by, the pace of new material; whether they feel ready to try an example with less support; etc.—works at three levels: cognitive, affective and metacognitive.

Such a learner-centred focus helps the teacher in the essential task of better matching teaching to the readiness of the learner in the (cognitive/conceptual) sense widely argued in constructivist writing. However, 'beyond cold conceptual change' (Pintrich, Marx, & Boyle, 1993), it also ensures that learners can *feel* challenged, yet not overstretched by learning. Not being bored, not being asked to do the trivial, not being too stressed and not being overwhelmed are important criteria to ensure students remain motivated and engaged and find learning chemistry a positive experience. Well-judged teaching leads to success in learning, which both improves academic self-concept and provides positive associations to learning the subject. In addition, actively inviting feedback on the learning experience in this way helps encourage a metacognitive attitude to learning and so invites learners to take on more responsibility for their learning (a theme explored further in Chap. 7). Taking ownership for their learning can support a sense of students being in control and allows them to take more satisfaction in successful learning. (It is also a pragmatic strategy for the teacher trying to fine-tune learning demands for large classes of different learners who have to be taught at the same time.)

In a sense, this sequence may help undermine one of the criticisms of formal education. We are all natural learners: inquisitive and driven to make sense of our environments. Yet, it is commonly argued that many students become disengaged in learning during secondary school because much of what they are taught is fairly meaningless to them and largely arbitrary in that they are the passive recipients of whatever a teacher's scheme of work determines should be taught on a particular day. The logic of formal education systems that include large classes and prescribed curriculum does not usually allow teachers to let students set their own agenda for classes according to the mood prevailing on a particular day. Nonetheless, a teaching approach informed by constructivist learning theory that regularly seeks feedback on students' sense-making *experiences* (and not just *the outcomes of* their sense making) could do much to help students re-engage their epistemic hunger.

It is often suggested that we need to show learners the relevance of the subjects we teach, and some chemistry teaching approaches seek to work through problems or contexts rather than being based on a sequence deriving from the conceptual structure of the subject. Yet, it might be suspected that 'intellectual relevance', through teaching that is designed to support perceptions of sense making, is just as important as 'everyday relevance' and may engage the natural epistemic hunger in many learners (Taber, Forthcoming). After all, those of us who are chemistry teachers certainly enjoyed learning chemistry, found it interesting and were motivated to learn more. Perhaps there is some reason why we were intrinsically interested in the subject: but perhaps some of us responded to being able to make good sense of the teaching and that initiated a positive feedback cycle that kept us engaged and made us confident enough to put the required effort into further learning.

5.2 Implications for the Research Programme

The argument made in this chapter has taken well-established constructivist ideas about teaching, normally considered primarily from a cognitive perspective, and suggested that considerations from the affective domain reinforce the key principles posited as the basis of constructivist-informed chemistry teaching. If we accept, with Ausubel, that the most important single factor influencing learning is indeed what the learner already knows, then perhaps close behind might be how the learner experiences the processes of making sense of teaching and learning activities. Strangely, despite the central emphasis on 'making sense' in constructivist literature, most research judges that in terms of how the teacher or researcher views the learner's ideas, and not enough studies have focused on the 'making sense' processes as subjectively experienced by learners themselves (Brock, 2006). That certainly seems an important area for further research. Studies are needed to explore the extent to which learners may sometimes accept and appear committed to a new idea met in chemistry instruction more because of the social context—how other learners seem to respond to new ideas—than because they are persuaded of the logical strength of the arguments for the idea. If this seems a significant effect—and this would seem likely from the parallel with adoption of religious beliefs, for example (Cornwall, 1987)—then it is important to know the long-term implications for the robustness of student learning and whether effective instruction needs to be designed accordingly (e.g. to use initial socially induced commitment to an idea as a starting point for then developing a more cognitively principled foundation for commitment to the idea).

An important recommendation is that research that focuses on cognitive or affective features of learning in isolation needs to be supplemented by research that explores instructional approaches and teaching innovations by simultaneously considering both the learning that takes place and the learner experience.

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Evaluating the Affective Dimension in Chemistry Education

Sri Rahayu

Abstract Learning of scientific concepts, including chemistry concepts, is more than a cognitive process. Students' affect consists of constructs such as attitude, interest, motivation, self-concept, values, and (6) moral values. All these six constructs play an important role in chemistry learning or chemistry education in general. Measurement of the affective domain is done through the methods of observation and self-report (e.g., using a questionnaire). The use of the observational method is based on the assumption that the affective characteristics can be seen from the behavior or deed that is shown and the psychological reactions which accompany it. The use of self-report methods is based on the assumption that it is the individual who knows the affective state of himself/herself. For the purpose of assessing the affective dimension, five principles need to be considered by a teacher/researcher. These principles are (1) the purpose of assessment, (2) what will be assessed, (3) what instruments are available, (4) the quality of the instruments, and (5) how to interpret the scores gained from the assessment process. In this chapter, I will discuss these principles.

Keywords Affect • Attitude • Assessment • Interest • Motivation • Morals • Self-concept • Values

1 Introduction

Education in general tends to stress the cognitive domain (Bisman, 2004). The affective domain has not been a central part of instruction and assessment in schooling (Holbrook, 2005). However, on the basis of constructivism in science education, affect has emerged as an important aspect of learning, inseparable from cognition (McLeod, 1992). Students' affect, which is often described as interest, attitude, and perception of how well they perform in learning contexts, could play an important role in developing meaningful understanding of scientific concepts (Nieswandt, 2007). Therefore, learning of scientific concepts, including chemistry

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concepts, is not merely a cognitive process (Garritz, 2010) but also involves the affective dimension.

There is no doubt that affect is one of the most important influences on the way students think and behave in social situations like in a classroom, but in practice how and why these cognitive and affective influences occur is not fully understood (Forgas, 2001); at the same time research studies exploring the link between the affect and a meaningful understanding of scientific concepts are limited (Nieswandt, 2007). Moreover, relatively limited research in science education has explicitly addressed affect, whereas there is a large research literature on attitudes about school science, which raises substantial epistemological issues (Reiss, 2005).

Researchers often use the word "attitudes" in a variety of ways and interchangeably with such terms as "interest" and "motivation" or together with such terms as "views" and "image." The definitions, interpretations, or explanations of the terms appear to involve a significant degree of overlap (Ramsden, 1998). The reasons for the limited attention that has been given to the affective dimension in educational settings may be due to difficulty in developing attitudinal and value-oriented instruction, its poor conceptualization, its highly individualized nature, and the difficulty in directly assessing it (Neuman & Friedman, 2010). The affective domain can only be inferred based on what is heard or witnessed (Forgas, 2001).

2 The Concept of Affect

The noncognitive aspects of human activity encapsulated in the word "affect" have been difficult for the psychological community to define, and there is not much agreement on how to describe them (Schlöglmann, 2010). Some psychologists state that the affect concept, arguably the most complex, is rooted in the emotional life of the student (Neuman & Friedman, 2010).

To be able to measure affect, the first step is to operationally define the term. What precisely do we mean by affect? The term affect has its origin in the Latin *affectus*, meaning feelings. From a research perspective, the affective domain includes a host of psychological constructs and is often described as attitudes, values, beliefs, opinions, interests, and motivation (Forgas, 2001). Krathwohl, Bloom, and Masia (1964) outline the best-known use of the term affect in the handbook *Taxonomy of Educational Objectives: The Affective Domain*. They consider "affective" to be a generic term describing such phenomena as emotions, attitudes, beliefs, moods, and conation. There are several characteristics of the affective domain, i.e., attitude, interest, motivation, self-concept, values, and morals. The following are descriptions of those characteristics.

2.1 Attitude

Attitude has a wide range of definitions. However, it is generally agreed that attitude is a tendency to think, feel, or act positively or negatively toward objects in our environment (Eagly & Chaiken, 1993). Regardless of the origin of attitudes, the term *attitudes* is reserved for evaluative tendencies which can both be inferred from and have an influence on belief, affect, and behavior (Albarracin, Johnson, Zanna, & Kumkale, 2005). Social psychologists have viewed attitudes as having three components, namely, the cognitive, the affective, and the behavioral components (Eagly & Chaiken, 1993). These components best represent the type of responses that allow researchers to diagnose attitudes. The cognitive component is a set of beliefs about the attributes of the attitudes' object, and its assessment is performed using self-report or paper-and-pencil tests (i.e., questionnaires). The affective component includes feelings about objects; and its assessment is performed using psychological indices, for example, heart rate, sweaty palms, constricted breathing, dry mouth, and other symptoms that describe the body's reaction to an affective, emotional experience. Finally, the behavioral component pertains to the way people act toward the object, and its assessment is performed with directly observed behaviors. For example, in a chemistry lesson incorporating an inquiry activity, a teacher can observe students' behaviors. If students have positive attitudes toward the learning activity, the teacher can observe their behaviors through (a) students' efforts in doing such an activity, (b) students' looking very enthusiastic during the activity, and/or (c) students' spending time to read the textbook for formulating their hypothesis in the activity. Students with more positive attitudes toward science show increased attention to classroom instruction and participate with greater interest in science activities (Germann, 1988).

2.2 Interest

Interest plays an important part in the learning process, determining, in part, what someone chooses to learn and how well he/she learns information (Garner, 1992). Interest has been conceptualized by researchers both as an individual predisposition and as a psychological state. The psychological state is characterized by focused attention, increased cognitive and affective functioning, and persistent effort. Moreover, interest affects the use of specific learning strategies and how a person allocates his/her attention (Hidi, 1990). It also affects his/her emotional engagement in a task and the extent to which he/she engages in deeper processing (Schiefele, 1999).

Based on how it has been viewed and researched, interest is separated into individual interest and situational interest. Psychologists conceptualize individual interest as:

> a continually evolving relation of a person and particular subject content that is at once somewhat idiosyncratic psychological state of being interested and also a process of internalization through which a person comes to identify and be identified with the content. (Renninger, 2000, p. 375)

Individual interest develops slowly, tends to be long lasting, and is associated with increased knowledge and value (Renninger, 2000). For example, a person with an individual interest in biomass and energy conservation seeks opportunities to engage in associated activities and while doing so experiences enjoyment and expands his/her knowledge. In contrast, situational interest is assumed to be transitory, environmentally activated, and context-specific. It is a kind of spontaneous interest that appears to fade as rapidly as it emerges and is almost always place-specific. It may or may not have a long-term effect on individuals' knowledge and value (Murphy & Alexander, 2000). For example, when students with a situational interest toward an inquiry activity are asked to report on a questionnaire, they will show positive perceptions on, for example, (a) their engagement and competence in doing inquiry activities, (2) the learning environments (i.e., they enjoy and like the learning environment), and (3) their positive outcome expectations (Rahayu, Chandrasegaran, Treagust, Kita, & Ibnu, 2011). If students are engaged in a learning environment in which they can actively connect the instruction to their interests and present understandings, then learning will be enhanced (Wise, 1996). Researchers agree that individual and situational interest affect learning in a variety of ways (Hidi, Renninger, & Krapp, 1992).

The distinction between the terms situational and individual interest has since been verified empirically. Situational interest has been shown to positively influence cognitive performance in areas such as focusing attention, enabling integration of information with prior knowledge, and enhancing levels of learning. Similarly, individual interest has been found to have a positive impact on attention, recognition, recall, persistence and effort, academic motivation, and levels of learning (Hidi & Renninger, 2006). Moreover, the positive effect associated with the levels of interest generated from both situational and individual factors has been found to contribute to cognitive performance (Ainley, Hidi, & Berndorff, 2002).

2.3 Motivation

Motivation is an internal state that arouses, directs, and sustains students' behavior and is important because students cannot learn unless they are motivated (Palmer, 2009). Therefore, researchers who have studied motivation attempt to explain why students strive for particular goals when learning chemistry, how intensively they strive, how long they strive, and what feelings and emotions characterize them in this process (Glynn & Koballa, 2006). Motivation would be required initially to make students want to participate in learning and would then be needed throughout the whole process of learning. Motivation is therefore an essential prerequisite and corequisite for learning.

Motivation includes important constructs such as intrinsic and extrinsic motivation, goal orientation, self-determination, self-efficacy, and assessment anxiety (Glynn & Koballa, 2006). Students often perform tasks for reasons that are both intrinsically and extrinsically motivated. For example, students who are intrinsically motivated to learn in a laboratory project often experience a flow—a state of concentration or being fully immersed, a feeling of energized focus, full involvement, and enjoyment in the process of the project (Csikszentmihalyi, 2000). They may also be extrinsically motivated by the prospect of receiving a prize from their teacher if they are able to complete the project.

2.4 Self-Concept

Self-concept is a description of one's own perceived self, accompanied by an evaluative judgment of self-worth (Pajares & Schunk, 2001). In specific terms, it is his/her attitudes, feelings, and knowledge about his/her abilities, skills, appearance, and social acceptability (Byrne, 1984). The construct of self-concept is potentially important and useful in explaining and predicting how someone acts (Bong & Skaalvik, 2003). One's perceptions of himself/herself are thought to influence the ways in which he/she acts, and his/her acts in turn influence the ways in which he/she perceives himself/herself, such as what attributes *they think* they possess, what roles *they presume* they are expected to play, what *they believe* they are capable of, how *they view* their feelings in comparison with others, and *how they judge* the way they are viewed by others. Seven features can be identified as critical to the construct definition. Self-concept may be described as organized, multifaceted, hierarchical, stable, developmental, evaluative, and differentiable.

Self-concept has received a great deal of attention in education and educational research. The enhancement of students' self-concept is a desirable educational goal throughout the world (Burnett, Craven, & Marsh, 1999). Individuals' knowledge and perceptions about themselves in achievement situations refer to academic self-concept or a subject self-concept. The attainment of positive academic self-concepts has been shown to affect academic behaviors, academic choices, educational aspirations, and subsequent academic achievement (Byrne, 1984).

The most commonly used method of measuring the construct is self-report. Items/statements that are typically used to assess academic self-concept include "I learn quickly in most academic subjects" and "I am good at combining ideas in ways that others have not tried." Items that are typically used to assess chemistry self-concept include "I am quite good at dealing with chemical ideas" and "I find chemistry concepts interesting and challenging" (Bauer, 2005). Students indicate how much they agree with each of these statements on, for example, 1–5, 1–7, or 1–11 response scales.

2.5 Values

Values can be defined as learned, relatively enduring, emotionally charged, epistemologically grounded, and represented moral conceptualizations that assist people in judging and preparing them to act (Frey, 1995). In other words, the priorities someone has set and the choices he/she makes are significantly based upon the values he/she holds. Values include both the personal values of an individual and the collective values of a community:

1. All values are *learned* values. [. . .] Values are transmitted and inculcated through an intricate web of societal agents and interactions. [Examples of] this web are family members and social peers [and] formal schooling [. . .]. The influence of this web is particularly important during childhood when the basic value parameters are established. In turn, these parameters help orient the subsequent acquisition and the reaffirmation of values throughout a person's life- span. [. . .]
2. Values are relatively *enduring*. Values are grounded in the cultural heritage of a society and pervasively housed within the institutions of the society, the web. And values are well established from childhood. [. . .] The values of a society or an individual are not easily altered.
3. Values are *not* necessarily *consciously* known by either the individual or the society. [. . .] Values are seldom overtly articulated, even though we depend upon both in comprehending another's action and in generating their own. [. . .]
4. Values tend toward *consistency*, i.e., like values attract like values. [. . .] If a particular value is not consistent with the assemblage of values already held, it is not easily integrated and is often ignored and excluded. [. . .]
5. Values enshrine and impart a society's concepts of the *morally desirable*. Values set forth the social criteria for and the cultural assumptions upon which good and bad, right and wrong, moral and immoral, noble and vile are established. [. . .]
6. Values are covered with *emotional* feelings and are held with strong conviction. There can be no passively neutral values. Fear, sympathy, hate, love, anger, passion, contempt: all are expressions of this subjective dimension of values. Values are most assuredly felt. [. . .]
7. Values are the great *motivators* within a society and the individual; the drive directed toward all sorts of ends. [. . .]
8. Values establish a *disposition to act*. Values influence our behaviors by preparing us to act in certain morally-oriented ways. When a certain behavioral response is called for in a given context of social interaction, what that behavior may be is based in part upon the values held. [. . .]
9. Any given value is based upon and expressed in terms of certain *epistemological criteria*. Upon what standard of knowing is a particular value acknowledged and represented? How is a particular value validated by the holder of that value? In what terms is a value framed and publicly presented? (Frey, 1994, pp. 19–22, numbers added for clarity)

Rokeach (1973) proposed 18 values, some of which are appropriate to be addressed in chemistry education, for example, ambitious (hardworking and aspiring), broad-minded (open-minded), capable (competent and effective), clean (neat and tidy), helpful (working for the welfare of others), honest (sincere and trustful), imaginative (daring and caring), independent (self-reliant and self-sufficient), intellectual (intelligent and reflective), logical (consistent and rational), responsible (dependable and reliable), and self-controlled (self-disciplined).

2.6 Morals

Morals (also sometimes called "morality") generally refer to behavior that conforms to codes of conduct that are held to be authoritative in matter of right and wrong. There are four component models of morality developed by Rest (in Fowler, Zeidler, & Sadler, 2009):

> Moral sensitivity is the ability to recognize when a situation contains a moral aspect. When confronted with a situation [. . .], a person with moral sensitivity is aware of how possible resolutions of the situation have the potential to affect others in a negative manner. Thus, [. . .] [she/he with moral sensitivity will be] able to examine aspects of a situation and the importance of each to that particular situation. (Fowler et al., 2009, p. 281)

> Moral reason is the analysis that is used to determine which course of action is morally desirable in a given situation and the ability to defend that position through the use of critical thinking skills. (Fowler et al., 2009, p. 281)

> Moral commitment is the priority to moral concern which requires a person to recognize that "personal concerns are not always compatible with the moral course of action followed by a willingness to choose what he or she has deemed the most moral course of action." (Fowler et al., 2009, p. 282)

> Moral courage [is] closely linked to moral commitment. [. . .] A person may recognize a moral situation, reason a moral course of action and be willing to follow the moral course of action, but at times, a person may encounter pressure from others not to do so. Though willing to follow a moral course of action (i.e., having moral commitment), a person also needs moral courage in order to do follow through. (Fowler et al., 2009, p. 282)

3 Assessment of Affective Dimensions

Evaluation is often equated and confused with assessment, but the two concepts are different. *Evaluation* is defined in education as the formal determination of the quality, effectiveness, or value of a program, project, process, objective, or curriculum. *Assessment*, conversely, is defined as a systematic process for collecting information in the form of quantitative and qualitative data, usually in measurable terms, about students' performance. Assessment provides important information for many different purposes that are important to the educational system, including guiding instructional decision-making in the classroom, holding schools accountable for students' achievement, and monitoring and evaluating educational programs (Coffey, Douglas, & Stearns, 2008). Moreover, assessment should be an integral part of teaching, not only as a tool to collect data, but also to influence instruction (Higuchi, 1995; Tej, 1990). Evaluations often utilize assessment data along with other resources to make decisions about revising, adopting, or rejecting a course or program. Thus the assessment or evaluation of students' performance should ideally cover cognitive (i.e., knowledge/intellectual), affective (e.g., values, attitudes, interest, and motivation), or social and psychomotor aspects of learning in line with the specific requirement of the particular lessons.

For the purpose of assessing the affective dimension, Anderson and Anderson (1982) suggest five principles to be considered by teachers/researchers in which they should know: (1) the purpose of assessment, (2) what will be assessed, (3) what instruments are available, (4) the quality of the instruments, and (5) how to interpret the assessment scores.

3.1 The Purpose of Assessment

Anderson and Anderson (1982) identify two major purposes for assessing affective characteristics. They are (1) to gain a better understanding of students prior to instruction and (2) to examine the extent to which students have acquired the affective objectives of a course or curriculum. In the first situation, affective characteristics are means to an end in which the assessment enables the instruction to be altered for particular students or types of students with the hope that such alterations will lead to increased learning. In the second situation, affective characteristics are ends in themselves, that is, specific programs are designed and implemented in order to help students achieve particular affective objectives.

Whether affective characteristics are important as means to an end or ends in themselves has consequences for the type of characteristics assessed. If they are viewed as means, those chosen for assessment must relate one or more of the available alternative classroom settings or teaching styles to the cognitive objectives of the course or curriculum, or both. If they are viewed as ends in themselves, the characteristics selected for assessment must conform to the goals and objectives of the course or curriculum.

The chemistry education literature describes instruments that are used to assess six different affective characteristics, including (1) attitude, (2) interest, (3) motivation, (4) self-concept, (5) values, and (6) morals. These characteristics will be discussed throughout this chapter:

1. An attitude instrument is intended to measure students' attitude toward an object, such as a chemistry lesson. The attitude can be positive or negative.

The measurement results of students' attitude can be used, for example, to decide an appropriate teaching strategy (Oliver-Hoyo & Allen, 2005).

2. An interest instrument is intended to get information about, for example, students' interest toward hands-on chemistry activities. The interest can be positive or negative. The information on students' interest can be used for designing a chemistry lesson (Palmer, 2009).
3. A motivation instrument is intended to measure, for example, students' learning motivation in chemistry. Students' motivation can be positive or negative. The information about students' motivation can be used to design a chemistry instructional program (Rahayu et al., 2011).
4. A self-concept instrument is intended to measure the strengths and weaknesses of students, for example, students' self-concept as a learner of chemistry (Bauer, 2005). The learner evaluates objectively against the potential that exists within him/her. The characteristic of the learner's potency is very important to determine the level of his/her career. Information on strengths and weaknesses of learners is used to determine which programs should be pursued.
5. A values instrument is intended to uncover the values of learners. Information obtained in the form of values can be positive or negative. Values that are positive can be strengthened, while negative values should be reduced and finally eradicated.
6. A morals instrument aims to uncover the learner's morals. Information about the learner's morals can be obtained through observation of behavior that is displayed and self-reports through administering a questionnaire. The results of observations and questionnaires provide information about the morals of the learners.

3.2 What Will Be Assessed

Affective characteristics refer to human qualities that are primarily emotional in nature, such as attitudes, interest, motivation, values, self-concepts, and morals. To be considered accessible, affective characteristics must be (1) emotion-laden qualities, (2) consistent across a variety of situations, (3) directed toward some object or target, and (4) experienced with a certain degree of intensity (Anderson & Anderson, 1982).

The meaningfulness of assessment is greatly enhanced if the various components of affective characteristics are defined. First, the particular object or target should be identified. For example, is the target of attitudes the school or the teacher? Is the target of interest an inquiry activity or a museum visit? Second, the degree of intensity of the affective characteristics should be specified. Some feelings are stronger than others, such as love is stronger than like. Some people may have feelings that are stronger than others. The endpoints of representing the directionality of the specific affective characteristics should be determined. Direction of feeling is connected with a positive or negative orientation of feeling and indicates whether the feeling is good or bad. For example, like toward lesson is positive, while anxiety is negative. Specifying the target, intensity, and directionality helps the assessor understand and communicate to others the affective characteristic to be assessed.

3.3 What Instruments Are Available

Once the purpose of assessment and the nature of the characteristic being assessed have been determined, the next step is to examine available instruments. Once a researcher finds an instrument, Creswell (2008) suggests several criteria that can be used to assess whether it is a good instrument to use. Ask yourself:

- Have authors developed the instrument recently, and can you obtain the most recent version? [. . .] To stay current, authors update their instruments periodically, and you need to find the most recent copy of an instrument.
- Is the instrument widely cited by other authors? Frequent use by other researchers will provide some indication of its endorsement by others [. . . and] may provide also some evidence about whether the questions on the instrument provide good and consistent measures.
- Are reviews available for the instrument? [. . .] If reviews exist, it means that other researchers have taken the instrument seriously and seek to document its worth.
- Is there information about the reliability and validity scores from past uses of the instrument?
- Does the procedure for recording data fit the research questions/hypotheses in your study?
- Does the instrument contain accepted scales of measurement? (Creswell, 2008, pp. 168–169)

Besides the above criteria, it is also important to consider whether the instrument was developed in a language or culture that is different than your own.

An example of an instrument designed to measure student attitudes is the Test of Science Related Attitudes, TOSRA (Fraser, 1981). TOSRA has been carefully field tested and has been shown to be highly reliable. It includes seven scales: social implications of science, normality of scientists, attitude toward scientific inquiry, adoption of scientific attitudes, enjoyment of science lessons, leisure interest in science, and career interest in science. TOSRA has been used in many research applications to track attitudes and evaluate interventions.

Another example of an instrument designed to measure students' views on science–technology–society was reviewed by Osborne, Simon, and Collins (2003). The instrument was developed by Aikenhead & Ryan (1992) and is often seen as offering greater validity than others. It has been adapted most recently by Bennett (2001) to determine undergraduates' views of chemistry and develop profiles of students who held positive and negative views of the chemistry subject.

If an affective instrument is not available, a researcher/teacher can develop one. According to Anderson (1981), there are two methods that can be used to measure the affective domain, i.e., using the methods of observation and self-report. The use of *observational method* is based on the assumption that the affective characteristics can be seen from the behavior or conduct that is displayed and/or psychological reactions. *Self-report* method is based on an assumption that a person knows his/her own affective state; it, however, demands that a person is honest in uncovering the characteristics of his/her own affect.

3.3.1 Developing a Self-Report Instrument for the Affective Dimension

If an affective instrument is not available, a researcher/teacher can develop one. According to Anderson (1981), there are two methods that can be used to measure the affective domain, i.e., using the methods of observation and self-report. The use of *observational method* is based on the assumption that the affective characteristics can be seen from the behavior or conduct that is displayed and/or psychological reactions. *Self-report* method is based on an assumption that a person knows his/her own affective state; it, however, demands that a person is honest in uncovering the characteristics of his/her own affect.

There are seven steps in developing a self-report instrument to assess the affective dimension. These are: (1) determine the specifications of the instrument, (2) write the instrument, (3) determine the scale of the instrument, (4) determine the scoring guidelines, (5) examine the instrument, (6) assemble the instrument, and (7) trial the instrument. The following are the explanations of each step:

1. Specifications of the Instrument

In determining the specifications of the instrument, a teacher/researcher needs to pay attention to: (1) the purpose of the instrument, (2) the blueprint of the instrument, (3) the format of the instrument, and (4) the length of the instrument.

After determining the purpose of the affective measurement, the next activity is constructing the blueprint of the instrument. The blueprint is a matrix containing the specifications of the instrument to be written (Table 1). The first step in determining the blueprint is determining the conceptual definitions derived from the theories that are taken from textbooks or the literature. Next, an operational definition is developed based on basic competencies, i.e., measurable competencies. The operational definition is then divided into a number of indicators. The indicator is a guide in writing instruments. Each indicator can be developed into two or more statements in the instruments.

Table 1 Blueprint of the affective instrument

No	Indicator	Number of items	Question/statement	scale
1				
2				
3				

2. Writing the Instrument

Table 1 is the blueprint of the affective instrument.

The following are examples of indicators and statements that should be written in the blueprint.

Instrument of Motivation in Learning Chemistry Motivation is an internal state that arouses, directs, and sustains students' behavior and has constructs such as intrinsic and extrinsic motivation, goal oriented, self-determination, self-efficacy, and anxiety (Glynn & Koballa, 2006). For example, the goal-oriented construct has two indicators—*performance goal* and *achievement goal*—which can be measured using the following statements:
Indicator: Performance Goal

- I participate in science courses to get a good grade.
- I participate in science courses to perform better than other students.
- I participate in science courses so that other students think that I'm smart.

Indicator: Achievement Goal

- During a chemistry course, I feel most fulfilled when I attain a good score in a test.
- I feel most fulfilled when I feel confident about the content in a chemistry course.
- During a chemistry course, I feel most fulfilled when I am able to solve a difficult problem.
- During a chemistry course, I feel most fulfilled when the teacher accepts my ideas.

Instrument of Self-concept Self-concept is a description of one's own perceived self accompanied by an evaluative judgment of self-worth. One of the indicators concerning self-concept of the chemistry subject is self-concept of ability. The statements for the indicator could be the following:

- I am good at chemistry.
- Chemistry content is rather easy for me to learn.
- I solve chemistry exercises very easily.

Instrument of Morals Morality is behavior that conforms to some code of conduct that is held to be authoritative in matters of right and wrong. For example, morals in chemistry have an indicator of awareness of science and societal issues. The following are the examples of items or statements used to assess students' morals relating science and society:

- Without the industrial chemical reduction of atmospheric nitrogen, starvation would be rampant in third-world countries.
- The danger of asbestos that is used for tiles and insulation in buildings is insufficient to warrant the high cost of its removal.
- Fossil hydrocarbons are too valuable as a source of recyclable plastic to be burned for fuel.
- The chemical industry took responsible action when confronted with evidence that the ozone layer was being depleted by fluorocarbons.
- Taking anabolic steroids for body building is in principle no different from administering growth hormones to persons with inherited dwarfism (see White, Brown, & Johnstone, 2005, p. 1572).

3. Determine the Scale of the Instrument

The scales that are often used in the affective instrument are the Likert scale, Thurstone scale, and the semantic differential. Likert scales are one of the most commonly used scales in social science research. The scale is named after its creator, psychologist Rensis Likert. On a survey that uses a questionnaire, the Likert scale typically has the following format: "Strongly agree," "Agree," "Neither agree nor disagree," "Disagree," and "Strongly disagree." An example of Likert scales for motivation in learning chemistry is shown in Table 2.

The Thurstone scale is made up of statements about a particular issue. Each statement has a numerical value indicating the respondent's attitude about the issue, either favorable or unfavorable. People indicate with which of the statements they agree on an 11-point response format (1 very negative to 11 very positive). The example of a Thurstone scale for self-concept in chemistry is shown in Table 3.

The semantic differential provides information on differences ("differential") in word usage ("semantics") in subjects. A learner (or respondent) is presented a sheet of paper with a single word or term at the top of the page. Below this word are a number of adjectival pairs, separated by seven blanks. The learner checks the cell which fits with what he/she feels about the word at the top of the page. For example, the meanings associated with the term "working with other students in a group" might be formatted as follows (Table 4).

4. Determine the Scoring Guidelines

The scoring system used depends on the scale of measurement. When using the Thurstone scale, the highest score for each response is 11 and the lowest score is 1 when the statement is a positive statement. Similarly, for instruments using a semantic differential scale, the highest score for each response is 7 and the lowest score is 1. For the Likert scale, the score given for each response depends on whether the statement is positive or negative. The person who "strongly agrees"

Table 2 Example of Likert scales

No	Statements	Scale				
		Strongly agree	Agree	Undecided	Disagree	Strongly disagree
		5	4	3	2	1
1	I participate in science courses to get a good grade					
2	I participate in science courses to perform better than other students					
3	During a chemistry course, I feel most fulfilled when I attain a good score in a test					

Table 3 An example of a Thurstone scale

No	Statement	Scale										
		1	2	3	4	5	6	7	8	9	10	11
1	I am good at chemistry											
2	During a chemistry course, I feel most fulfilled when I am able to solve a difficult problem											
3	Chemistry content is rather easy for me to learn											

Table 4 Example of a semantic differential scale

	Working with other students in a group							
	Very	Quite	Some	Neither	Some	Quite	Very	
Friendly								Unfriendly
Fun								Bored
Good								Bad

with a "positive statement" gets the maximum score 5. One who "strongly disagrees" with a "negative statement" gets the minimum score 1.

The total score gained by a respondent/learner can be analyzed for level of the learner, i.e., by finding the average (mean) and standard deviations of the score. Furthermore, the findings are interpreted to identify the affective characteristic (e.g., attitude, motivation, self-concept, etc.) of each respondent/learner.

5. Examining the Instrument

The affective instrument should be reviewed in order to determine whether: (1) the statement in each item is in accordance with its corresponding indicator, (2) the language used sounds communicative and grammatically correct, (3) the statement in each item is unbiased, (4) the format of the instrument is attractive to be read, (5) the guidelines on how to complete the instrument are clear, and (6) the number of items and/or the length of statement is appropriate so that the learner does not feel bored to answer the instrument.

The review process should be conducted by a panel of experts. Sometimes the review process can be conducted by a panel of colleagues, especially when there is a need to consider whether the language and format of the instrument is suitable for the level of learners.

The length of the instrument is related to the problem of boredom in responding to the items in the instruments. The length of time to respond to the instruments should be no more than 30 min.

The first step in writing a question/statement is to determine what information the researcher/teacher wants to obtain, the structure of the question/statement, and the choice of vocabulary. A question/statement proposed should be unbiased and not directing the respondent to a certain positive or negative choice.

Results of the review process are used to improve the instrument. Improvements are made to the construction of the instrument, i.e., the sentences used, the time it takes to complete the instrument, how to respond to the instrument, and the type setting.

6. Assembling the Instrument

After modifying the instrument, the next step involves assembling the instrument, specifying the format of the layout of the instrument and the order of questions/statements. The format of the instrument should be made interesting and not too long, so that respondents are interested in reading and responding to the items. The questions/statements are sorted in accordance with the level of ease in answering.

7. Trialing the Instrument

After assembling the self-report instrument, a teacher/researcher trials out it with the respondents. The respondents can be students, teachers, or parents of students depending on the purpose of the instrument. The respondents should be chosen to represent the characteristics of the population assessed. If the researcher wants to assess high school students, the trial sample should also be high school students. The size of the sample should be at least 30 students from one or more high schools.

At the time of the test, some notes need to be considered, such as the clarity of guidelines for completing the instrument, the clarity of the sentences being used, and the time required to complete the instrument. Since the self-report instrument is not a test, the time to complete the instrument should not be restricted. However, it is better to limit the time to about 30 min to obtain the best results.

3.3.2 Developing an Instrument for Observation

Assessment of the affective dimension can be done using a self-report in the form of a questionnaire or through observation. The procedure to develop the observation instrument is basically similar to the procedure to develop the self-report instrument. It begins with determining the conceptual and operational definitions of the construct. For example, if a teacher/researcher intends to assess the interest of students in a chemistry lesson, he/she must determine the indicators of the interest that can be observed *directly*. The indicators could be students' attendance in the classroom, willingness of students in doing a given task, the number of questions posed by the students, how completely students take notes, etc. The results of the observations provide additional information to a questionnaire in the same construct (i.e., interest of students in a chemistry lesson). Thus, results based on both direct observations and questionnaires will be more accurate in representing students' interest in a chemistry lesson than result based on data from only one of these sources.

3.4 The Quality of the Instruments

Trialing the assembled affective instrument is intended to examine its technical quality such as its communication value, objectivity, validity, reliability, and interpretability (Anderson & Anderson, 1982). Communication value means the extent to which the instrument is understood by the respondents. The indicators of having good communication value are that the instrument must show clear direction and the items are written at the reading level of the majority of the intended respondents.

Objectivity is the extent to which the scoring or coding of responses is free from scorer (or coder) error or bias. Thus, a set of scoring rules (or a scoring key) must be present and the qualifications of the persons doing the scoring must be specified in order to avoid bias.

Validity is the most important idea to consider when preparing or selecting an instrument for use in a study (Fraenkel & Wallen, 2006). It has been defined in recent years as referring to the *appropriateness*, *correctness*, *meaningfulness*, and *usefulness* of the specific inferences researchers make based on the data they collect and enables a researcher to draw meaningful conclusions from the sample he/she is studying about the population (Creswell, 2008). Validity depends on the amount and type of evidence there is to support the interpretations researchers wish to make concerning data they have collected. Essentially, there are three main types of evidence collected by a researcher:

- *Content-related evidence of validity* refers to the content and format of the instrument. How appropriate is the content? How comprehensive is the content? Does the instrument logically measure the intended variable? How adequately does the sample of items represent the content to be assessed? Is the format of the instrument appropriate?

- *Criterion-related evidence validity* refers to the relationship between the score obtained using the instrument and score obtained using one or more other instruments or criteria. How strong is the relationship between the variables? How well do the scores estimate the present performance or predict future performance of a certain type?
- *Construct-related evidence of validity* refers to the nature of the psychological construct or characteristics being measured by the instrument. How well does a measure of the construct explain differences in the behavior of individuals or their performance on a certain task? There are usually three steps in obtaining the construct-related evidence of validity, i.e., (1) the variable being measured is clearly defined; (2) hypotheses, based on a theory underlying the variable, are formed about how people will behave in a particular situation; and (3) the hypotheses are tested both logically and empirically.

Reliability means that scores from an instrument are stable and consistent. Scores should be nearly the same when the researchers administer the instrument multiple times on different occasions. Reliability estimates provide researchers with an idea of how much variation to expect, measured in terms of the *reliability coefficient* that ranges from 0.00 to 1.00, with no negative values (Fraenkel & Wallen, 2006). The three best-known ways to obtain a reliability coefficient are the test-retest method, the equivalent-form method, and the internal-consistency method:

1. *The test-retest method* involves administering the same test twice to the same group after a certain time interval has elapsed. The reliability coefficient is then calculated to indicate the relationship between the two sets of scores obtained.
2. *The equivalent-form method* is used when two different but equivalent forms of an instrument are administered to the same group of individuals during the same time. A reliability coefficient is then calculated between the two sets of scores obtained.
3. *The internal-consistency method* consists of several procedures/approaches of estimating reliability, requiring only a single administration of the instrument. The procedures/approaches are:

   (a) *The split-half procedure* involves scoring two halves (usually odd items versus even items) of a test separately for each person and then calculating a correlation coefficient for the two sets of scores using the *Spearman–Brown prophecy formula*.

   (b) *Kuder–Richardson approaches*, particularly formulas KR20 and KR21, are the most frequently used formulas for determining internal consistency.

   (c) *Alpha coefficient* (frequently called *Cronbach's alpha*) is another check on the internal consistency of an instrument.

Internal-consistency estimates of reliability for good affective scales tend to fall into the 0.80 s (Anderson & Anderson, 1982); such numbers indicate a high degree of consistency of responses to the items within a given instrument. Consistency of responses over time (or stability) is reported by authors of several instruments. When stability estimates are reported, they tend to range from 0.60 to 0.90 depending on the time interval and the nature of the affective characteristic being assessed. Such evidence supports the assumption that the instrument does, in fact, assess typical ways of feeling, a critical component of affective characteristics.

Reliability and validity are bound together in a complex way. These two terms sometimes overlap and at other times are mutually exclusive. Reliability generally is easier to understand as it is a measure of consistency. The relationship between reliability and validity can be explained like this: if scores are not reliable, they are not valid; scores need to be stable and consistent first before they can be meaningful. Additionally, the more reliable the scores from an instrument, the more valid the scores may be. However, scores may still not measure the particular construct and may remain invalid. The ideal situation exists when scores are both reliable and valid.

Interpretability is the extent to which the instrument provides information that can be understood by interested groups of people (Anderson & Anderson, 1982). Basically, the scores obtained from affective instruments are made meaningful by comparing them with other information. Therefore, interpretability is likely to be high if the writer of the instrument provides additional data that can aid in making meaningful interpretations. Such data would include: (1) the distribution of scores of a large group of same-age students to whom the instrument has been administered, (2) mean scores of a group of students known to differ to some extent on the affective characteristics being assessed, and (3) information about the point on the scale itself at which the directionality of the affective characteristics changes from positive to negative.

3.5 How to Interpret the Assessment Scores

Examination of the assessment scores of an affective instrument is required within the context of the purpose of the assessment and the nature of the characteristics being assessed to attain correct interpretation. In terms of the purpose of assessment, if the purpose of the assessment was to examine the extent to which an instructional program for teaching chemistry (e.g., the use of the learning cycle model, cooperative learning, or graphic organizer strategy) increases students' motivation, then the interpretation must focus on whether or not students' motivation has increased. If, on the other hand, the purpose of the assessment was to determine the type of instruction to be received by particular type of students (e.g., instruction that is oriented toward future careers in chemistry and instruction that is oriented toward everyday life), then the interpretation must focus on differentiating between students who would be more or less likely to benefit from different instructional approaches.

In terms of the nature of the characteristics being assessed, correct interpretation must also be consistent with the nature of the characteristics. If the characteristic is interest, then higher scores may be interpreted as indicating greater interest; but higher scores on an anxiety instrument could be interpreted as indicating debilitating levels of anxiety.

Affective characteristics can be important both as means and ends of education. Therefore, the assessment of these characteristics is equally important. A researcher/teacher may need to understand students' affective characteristics in order to provide proper instructional conditions and to evaluate an affective education program. For example, self-concept (e.g., academic/subject self-concept) has been considered as a desirable educational goal; we need to understand students' self-concept and provide the instructional conditions and settings that can enhance students' self-concept. In short, if the affective characteristics are viewed as means, those chosen for assessment must relate one or more of the available classroom settings or teaching styles to the cognitive objectives of the course or curriculum, or both. If they are viewed as ends in themselves, the characteristics selected for assessment must conform to the goals and objectives of the course or curriculum.

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Getting Involved: Context-Based Learning in Chemistry Education

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Abstract This chapter reviews influential theories of motivation and interest development to support the argument that emotional and affective aspects are crucial for attitudes toward and learning of chemistry in schools. Context-based learning approaches such as the German project *Chemie im Kontext* are reflected from the perspective of their ability to foster students' interest and motivation. The "RIASEC framework" is presented as a structure to design context-based teaching modules that match students' interests. Based on this framework, three examples of modules describe how different areas of interest can be explored in order to connect content knowledge to personal or societal questions. Empirical findings are discussed for one study investigating students' attitudes as well as their application of content knowledge. The results showed that using personally relevant contexts had mostly positive effects on students' motivation and interest; however, there were less satisfying results regarding students' application of content knowledge. This study suggests that, in some cases, an emotional identification with a topic might restrain the application of science concepts, e.g., in decision making. Recommendations for further research are proposed.

1 Introduction

Both positive affective dimensions and a persisting interest in science and science subjects (Krapp & Prenzel, 2011; Taconis & Kessels, 2009) are regarded as promoters of deeper conceptual understanding (Alexander, Kulikowich, & Schulze, 1994). It is therefore assumed that these factors also result in a higher number of students choosing science-related careers (Hazari, Sonnert, Sadler, & Shanahan, 2010; Osborne, Simon, & Collins, 2003; Schreiner & Sjøberg, 2007). Especially

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regarding the first assumption, Pintrich (1999) criticized that conceptual change approaches overrated cognitive aspects for a long time and therefore neglected their affective counterparts. Pintrich, Marx, und Boyle (1993) claimed that a conceptual change from daily-life explanations toward more scientific concepts was not solely a question of logic or consistency but also one of emotions. A student might like or dislike a scientific explanation, which might interfere with existing "entrenched beliefs" (Chinn & Brewer, 1998) or prejudices (Menthe, 2006). Such interferences can support or hinder further developments of conceptual understanding and, therefore, need to be considered in learning processes.

A number of publications still criticize the neglect of affective aspects, such as feelings, attitudes, motivation, or interest in science education (e.g., Alsop & Watts, 2003; Eccles & Wigfield, 2002; Hidi & Baird, 1986; Osborne et al., 2003). How can affective aspects be better integrated into science or, more specifically, chemistry teaching and learning processes? Approaches such as science-technology-society (STS, e.g., Aikenhead, 2006), context-based learning (CBL, Gilbert, 2006; King, 2009), or socio-scientific issues (SSI, e.g., Kolstø & Ratcliffe, 2007; Marks & Eilks, 2009; Ratcliffe & Grace, 2003) connect science concepts and principles of investigation to the students' real life and thereby claim to link cognitive and affective goals and preconditions.

Positive effects on students' interest have been reported especially for context-based learning approaches (Bennett, Lubben, & Hogarth, 2007; Nentwig & Waddington, 2005; Parchmann et al., 2006). Those effects can be connected to theories of interest and motivation that identify aspects which are explicitly taken into consideration in CBL approaches.

2 Frameworks of Motivation, Interest, and Attitudes as a Theoretical Foundation for Context-Based Learning

In this section, the general frameworks of interest and motivation are depicted. Their relation to the design of context-based learning environments will be addressed at the end of each subsection and then again with more details in the third section of this paper.

2.1 Motivation

What constitutes the intention or the desire to engage in something? How do students' attitudes, beliefs, values, and goals influence such intentions? These crucial questions are researched by motivational theories. A very influential motivation theory is the self-determination theory of Deci und Ryan (1985, 2000). In this theory, extrinsic motivation is related to external factors (e.g., the desire to have a good grade), whereas intrinsically motivated behavior is performed for its own sake, based on interest and enjoyment. The distinction between mastery versus performance goal orientation (and between different performance goal orientations) is related to these two kinds of motivation (Harackiewicz, Barron, Tauer, Carter, & Elliot, 2000). Mastery and performance goal orientations can coexist, for example, influenced by a certain situation or the school environment (Vedder-Weiss & Fortus, 2012).

Intrinsically motivated behavior is performed voluntarily, without external incentives, and is autotelic (Csikszentmihalyi, 1975). However, different states of motivation can be distinguished. Whereas, in the former conceptualizations, extrinsic and intrinsic motivation had been seen as two diverse poles, Deci und Ryan (1985) described steps between purely intrinsic and purely extrinsic motivation. Those steps can also be understood as the development of more stable and long-lasting attitudes and interests and are, therefore, closely connected.

In their influential self-determination theory, Deci and Ryan developed the basic psychological needs concept, an "organismic theory" to explain why certain kinds of activities are motivating (Deci & Ryan, 1985, 2000; Krapp & Prenzel, 2011). They identified three basic needs as highly important for motivation: the perception of autonomy, of competence, and of social embeddedness. For school education, Prenzel (1997) extended these needs by three additional factors: the perception of relevance, the interest of the educator, and the quality of instruction.

In context-based learning, the perception of relevance is given special consideration (Nentwig, Parchmann, Gräsel, Ralle, & Demuth, 2007). For chemistry education, most topics can be made relevant by highlighting the chemistry applied in daily-life products and processes, such as batteries, clothes, or societal debates about topics like climate change. By emphasizing the relevance of a topic for the student in different ways, CBL aims at fostering mastery goal orientation, which is claimed to be supportive for learning processes (Vedder-Weiss & Fortus, 2012). Hence, context-based learning aims at fostering intrinsic motivation as a bridge toward the development of individual interests.

2.2 Interest

Interest can be differentiated as situational or personal interest, with personal interest being described as "stable evaluative orientation towards a certain domain" (Schiefele, 1999, p. 258). Situational interest is conceptualized as a temporary state which is elicited by specific features of a topic or learning situation. More elaborated taxonomies, including an overview of aspects that have been found to raise interest in learning, can be found in Hidi und Renninger (2006), Schraw und Lehman (2001), and Schiefele (1999).

One fundamental framework is the "person-object theory of interest" (Krapp, 2002) which assumes that interest results from an interaction between a person and an object and further assumes that this interaction is correlated with emotional as well as cognitive aspects (Schiefele, 2009). The person-object theory picks up the dichotomy of situational and personal interests and explains how a situational interest can become a personal interest over time due to positive cognitive (importance) and emotional (well-being) experiences. School in general and therefore also chemistry lessons have the important role of supporting children to broaden their view and of developing different and persistent interests (Krapp & Prenzel, 2011). Regarding chemistry, fields of personal interest can be related to topic areas like acids and bases or fuels, to contexts like daily-life habits or societal debates, and to activities such as experimental investigations and professional perspectives.

An approach linking personal and situational interest in different steps is the "four-phase model of interest development" (Hidi & Renninger, 2006). This model distinguishes phases of triggered situational interest, of maintained situational interest, of emerging (less-developed) individual interest, and finally of a well-developed individual interest (ibid.). The model conveys a similar understanding of interest as the person-object theory (for differences, see ibid., p. 118f) but differentiates between the role of affect (important for the early phases of interest development) and cognitive evaluations due to prior experience and knowledge (important in the later phases of interest development, ibid., p. 121).

Although research has been done about interest in other disciplines, little research has been done in the domain of science. A large study carried out in Germany characterized interest in science as an interplay of an interest in topics or content, contexts, and activities. Based on this structure, differences between boys and girls or between groups of students, for example, were identified and highlighted (Haeussler, Hoffman, Langeheine, Rost, & Sievers, 1998). Boys showed higher interests in physical topics, while girls had higher levels of interest in biological topics. Three groups of students could be identified as well: a rather small group showing high interest in all contexts related to science, a second group being interested in societal and environmental debates, and a third group showing high interests in applications of science.

Another differentiated model is the "RIASEC structure," developed by Holland (1997). This structure combines six dimensions of personal interest and analogous areas of professions, represented by the six letters RIASEC (Table 1).

In the original model, the science domain was only connected to the dimensions "realistic" and "investigative." However, in an ongoing research project (Dierks, Hoeffler, & Parchmann, 2014), we have successfully linked all dimensions to science-related activities (as described in Table 1). This adapted model allows an even more sophisticated analysis of students' interest in science-related contexts and activities, as presented below.

Context-based learning has shown to have positive impacts on students' interest (Bennett et al., 2007; Nentwig & Waddington, 2005). Following the person-object theory, CBL environments link the subject-matter content to the students' experiences and personal interests outside the classroom. The resulting interplay between the students and the learning objects is often broader than in more abstract approaches. Students will have different relationships to topics such as food, clothes, or their environment than to pure chemistry areas such as halogens,

Table 1 Dimensions and characteristics of the adapted RIASEC model (Dierks et al., 2014)

RIASEC dimension	Attributes	Example activities of scientists
R: realistic	Technically adept	Take samples, carry out procedures in a lab
I: investigative	Analytic	Interpret data and literature, research new aspects, develop analytical and complex research schemes
A: artistic	Creative	Create instruments, design presentations
S: social	Social, caring	Teach, supervise coworkers, engage in social projects
E: enterprising	Leading	Manage a project group, acquire funding
C: conventional	Precise, organized	Administer data, documentation

alkenes, or the reaction between hydrochloric acid and sodium hydroxide. This can influence their attitudes toward regarding chemistry as being relevant and present in everybody's daily life.

2.3 Attitudes

Attitudes toward science are often reported as negative (Hazari et al., 2010; Osborne et al., 2003). One reason for this is seen in the lack of characteristics fostering interest and motivation, as described above. Science classes often follow a narrow script; they are limiting students' ideas and are often perceived as strict and dogmatic, with little space for creativity (Donnelly, 2001).

Another reason is the existing stereotype of science and scientists in our society. Hannover und Kessels (2004) describe those stereotypes and highlight the mismatch between such images and the desired self-images of young people to explain the unpopularity of science among pupils/students. The assumed underlying mechanism is that pupils base subject choice both on task-value beliefs (e.g., expectancies; see below) and on a comparison of their self-image to a typical representative of the science culture (Taconis & Kessels, 2009). Those studies showed several remarkable results: (1) a representative of the science culture is attributed with more negative characteristics than the average student (more ego oriented, less social) and (2) the gap between the self-image and an envisioned stereotype of a successful science student is bigger for female students, which is assumed to be one reason for gender differences in subject choice.

A third problem underpinning the negative attitudes toward science is that science and mathematics are seen as difficult, abstract, and of little practical use in everyday life. Osborne et al. conclude "that a knowledge of science has no intrinsic cultural value" (Osborne et al., 2003, p. 1064). There seems to be little reason to engage in a subject where expectancy and task value are low and interest is hard to develop. This seems to be even more valid for female students, whose self-efficacy beliefs in science are also found to be lower than those of their male counterparts (Dickhauser & Meyer, 2006).

Context-based learning aims at relating science to the students' personal experiences and values, which is perceived and evaluated positively by students (Bennett et al., 2007; Gilbert, Bulte, & Pilot, 2011; Nentwig & Waddington, 2005). These approaches explicitly state the change of attitudes as one goal. Especially for chemistry education, at least two meanings of attitudes must be addressed: attitudes regarding the personal relevance of chemistry education (see above) and attitudes toward the importance, challenges, and benefits of chemistry for society. Negative images of chemistry as something dangerous that should be avoided, as represented in mass media, certainly influence students' attitudes in this area. Context-based learning does not neglect this but links it to positive developments and effects as well. A broader perspective might not only influence the students' attitudes but also allows a reflective decision making, as explored in the final part of this book chapter.

Role models and stereotypes have not been taken into consideration to the same degree in most CBL approaches yet. This link could be established by an additional reflection of chemists and their professional fields as part of the context dealt with in class.

The expectancy-value model, described in the next section, combines the criteria and frameworks we have explored so far into an integrated model.

2.4 The Expectancy-Value Theory

In the expectancy-value theory, motivation and action are regarded as driven by the expected or desired outcomes and by the estimation of one's own expected performance and ability (Eccles & Wigfield, 2002). According to this theory, personal choices are influenced by the value he/she attributes to a certain task and the probability of success he/she relates to a certain activity (perception of competence, perception of the difficulty of different tasks, and individuals' goals and self-schemata (Eccles & Wigfield, 2002). Task value comprises the extent to which an individual believes that a task can fulfill personal needs or goals. The authors discriminate three aspects of task value: personal interest, importance (to perform well on a task), and utility (how useful does the person consider the task for reaching future goals).

Expectancies and values comprise social aspects as well; beliefs are formed individually but in interaction with peers, teachers, or media, i.e., they are influenced by other peoples' attitudes. Eccles and Wigfield (2000) explicitly speak of "affective memories" that influence individual expectations. Such affections are often unconscious. A student might dislike science, without calculating the expectancies for success—but by coherently and subconsciously integrating his/her (and other peoples') experiences with science. Such a broad understanding of expectancies and values means that success can be perceived in different ways, for example, in relation to a given norm that is related to the development of a deeper understanding. However, as other research suggests, it can also be perceived as a wish to behave in accordance with the expectations of peers or a person's self-image (Hannover & Kessels, 2004; Taconis & Kessels, 2009).

The contextualization of chemistry content in CBL aims to increase task value by making the connection of the content with personal interest and (future) utility more obvious for the students. Following the expectancy-value-model, context-based learning should therefore have an influence on the students' choice of future science activities (Bennett et al., 2007).

3 Transformation of Theory and Research into Practice: Examples from the Context-Based Approach *Chemie im Kontext*

Chemie im Kontext was developed in Germany between 1999 and 2008, with the support of the German Ministry of Education (BMBF) and the participating German federal states. The process of development was symbiotic: educational researchers and teachers from different schools cooperated in "learning communities" (Parchmann et al., 2006) and adapted the framework of *Chemie im Kontext* for different state syllabi and school systems. Modules were developed and tested, and the different learning communities exchanged experiences and material between the different parts of Germany. The products were used as a foundation to develop textbooks, teacher guides, reports, and papers (e.g., Demuth, Gräsel, Parchmann, & Ralle, 2008; Demuth, Parchmann, & Ralle, 2006; Nentwig et al., 2007; Parchmann et al., 2006). Accompanying research studies have investigated different aspects affected by the implementation of the *Chemie im Kontext* approach, such as the students' interest and conceptual development (Demuth et al., 2008; Parchmann et al., 2006;), the implementation and transfer processes (Demuth et al., 2008), or the influence of attitudes and prejudices (Menthe, 2006, see below). Based on a study carried out in one federal state, a positive finding was that students indeed perceived their chemistry lessons as more relevant and effective regarding the learning of cross-curricular competencies, applicable knowledge, and the understanding of basic concepts. This finding became evident in a comparison with other students learning similar topics (Parchmann & I. und the CHiK team, 2009). However, we have to consider that effects were diverse on a class level. On the one hand, for some groups, motivation really increased, whereas, for others, it stayed more or less the same and even dropped at the beginning for some classes. The same is reported for cognitive learning outcomes: while CBL students outperformed others in some studies, other studies offered less coherent outcomes in this area (Bennett et al., 2007; Parchmann et al., 2006; Taasoobshirazi & Carr, 2008; see also Fechner, van Vorst, Kölbach, & Sumfleth, 2015). Therefore, more

Table 2 RIASEC dimensions related to context perspectives and activities

RIASEC dimensions	Activities within CBL modules
Realistic	Mimicry of technical procedures, measurements, and analyses of data by given procedures
Investigative	Analyses of data and literature to create new ideas, arguments, or products; research of new products
Artistic	Presentation of findings in creative ways (posters, exhibitions, articles, advertisement)
Social	Engage in socio-scientific-issues; discuss political decisions, relation to personal and general welfare, peer debates
Enterprising	Develop project plans; explore relations between research, industry and society, chances, and risks of technology
Conventional	Data storage, documentation of investigations

information is necessary in order to determine which specific aspects and approaches of CBL foster—or fail to foster—positive affective and cognitive outcomes in chemistry and other subjects.

The frameworks on motivation, interest, and attitudes informed the design of the *Chemie im Kontext* project and have been used as reflective tools in further studies (Nentwig et al., 2007; Parchmann et al., 2006). Referring to the theoretical background explored above, questions like the following had been discussed during the developmental process and the accompanying research:

How can we design modules to enable students' perception of autonomy, competence, social embeddedness, and relevance? (→ Students participate in the phase of planning by developing their own questions. They can choose between different activities in group work. The content is embedded in different personal, societal, and professional contexts.)

How can we link topics, activities, and contexts to build connections to students' different personal interests? (→ The design and combination of modules consider different dimensions; see Table 2 for the RIASEC dimensions.)

How can we highlight values of learning chemistry, stimulating positive attitudes and "affective memories"? (→ The design of the modules relates chemical content to different decision-making processes—see example below.)

To take different personal interests of students into consideration, the RIASEC model offers a suitable framework (Table 2). While CBL modules offer connections to almost all dimensions (see examples below), specific tasks and activities enable students to get engaged according to their personal interests.

In the following paragraphs, three examples of modules describe the adaption of theories and frameworks on motivation, interest, and attitudes in further details. The topics have also been explored by other CBL approaches, as summarized in Nentwig and Waddington (2007), for example.

3.1 Example 1: Fuels for Our Future: A Topic Not Only for Boys!

Fuels, both for combustion and electrochemical engines, are an important topic in many chemistry curricula around the world. The basic concepts needed to explain the functionality of fuels are the redox concept (or more general the concept of chemical reactions) and the energy concept. Relevant studies, however, such as ROSE showed that especially female students show little interest in these topics (Holstermann & Bögeholz, 2007; Jenkins & Nelson, 2005). For the development of *Chemie im Kontext* modules, we took these results into consideration and broadened the perspectives around the given topic. The modules not only consider technical and chemical aspects but also include social, societal, and economic/enterprising perspectives. The range of activities involves students' ideas (autonomy), group work, and links to out-of-school activities and relevant political and economic questions (social embeddedness). Different levels of tasks and areas of competence [such as subject-matter knowledge, scientific processes, communication, or evaluation, following the outline of the German standards (KMK, 2004)] aim at supporting the perception of competence for a range of students.

The structure of a module about the hydrogen car is briefly presented in Fig. 1. The content knowledge deals with redox reactions and the design and function of fuel cells. The students thereby learn about a technique that is already more than 100 years old but has only recently become promising again for societal reasons: the growing demand for mobility cannot be fulfilled anymore because of the shortage of crude oil and fossil fuels in the future.

During the exploration of the topic, the students become aware that they cannot decide against or in favor of this technique based solely on chemical knowledge. Other components about environmental considerations, prices, and supply or

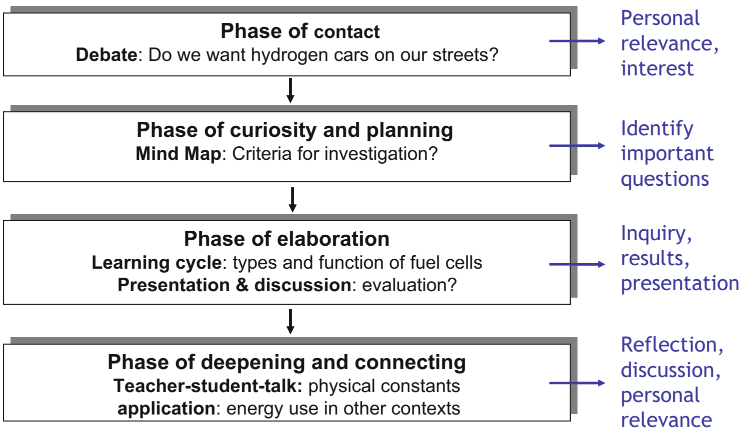

Fig. 1 *Chemie im Kontext* structure of the module on hydrogen cars and fuel cells (upper secondary level)

demands for the users need to be taken into account as well, offering links to different RIASEC dimensions (e.g., enterprising, social, investigative) and related students' interests, concerns, and attitudes. Career perspectives can be highlighted both in industry and research but also in education, public counseling, or infrastructure planning (e.g., for the supply of hydrogen). In summary, the module combines basic chemical concepts with societal demands and a variety of personal interest areas. Moreover, the module offers an opportunity to discuss and reflect on attitudes and arguments from science and other domains. Hence, the chemical content is connected to personal feelings and attitudes (risk, environmental issues). Consequently, both affective dimensions and cognitive variables have been taken into consideration.

3.2 Example 2: Carbon Dioxide, The Greenhouse Effect, and Climate Change

Climate change is very prominent in the media and in political discussions. However, media reports often show a lack of understanding and a mistaken explanation of its underlying effects, especially regarding scientific concepts and the relevance and barriers of model-based predictions. Following the criteria of interest, motivation, and attitudes, the topic offers a promising context for the development of a better understanding about scientific processes in the atmosphere and the nature of scientific investigation and evidence.

For the sub-module about carbon dioxide and its uptake by the oceans, chemical equilibrium has been chosen as the content to develop. Figure 2 shows the interplay of contextual aspects and the development of this basic concept.

Again, different interests can be approached by highlighting the different context perspectives: while some students might be interested in the underlying scientific investigations, others might want to know more about global political decisions. The module points out for all those aspects that chemical and science knowledge is necessary and should be the foundation for decision-making processes in politics, industrial developments, and personal behavior. However, students also experience

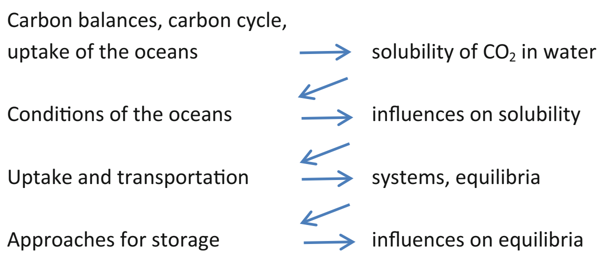

Fig. 2 Interplay of contextual aspects and the basic concept of the chemical equilibrium

that science knowledge on its own is not enough for this: it has to be connected to other domains and it is guided by norms and ethical issues as well.

In summary, the module links personal interests and attitudes with a scientific understanding and thereby raises the level of argumentation both in class and also outside the classroom. Cognitive understanding is the foundation for such debates and is applied on a "need-to-know basis."

3.3 Example 3: Tap Water or Mineral Water: Decision Making and Attitudes

This unit focuses on the idea of combining necessary chemistry content with a relevant personal decision: should you prefer tap water or bottled mineral water for drinking? The unit is based on teaching materials developed by two teachers (T. Guenkel and W. Muenzinger) who designed a sequence with lab work and useful information framed by the abovementioned question. The content of the unit is based on the students' interests, as they pose the research questions and organize the work. Various experiments (e.g., How do minerals or CO_2 get into water? How can we measure the amount of minerals? Which water tastes better?) and information (Which minerals are healthy? What does the information on the labels mean?) are offered. The activities allow a high degree of autonomy for the students throughout the lessons and build upon their personal interests to enhance motivation. The unit ends with a role-play where students are divided into groups (e.g., nutritional advisers, producer of mineral water, local water supplier, etc.). In these groups, they relate chemistry knowledge and the given position of the interest group they have chosen. In a symposium, they discuss the advantages and disadvantages of the two types of water.

In a pre/posttest design (before the unit and after lab work and role-play), all students were asked to give a personal report of their choice between the two kinds of water and to provide reasons for their choice. Decision-making processes were analyzed by the qualitative content analysis method (Mayring, 2000). The aim was to clarify the extent to which students use science knowledge in their reasoning on socio-scientific issues (Aikenhead, 2006; Kolstø & Ratcliffe, 2007). The literature shows that students often make little use of newly acquired scientific evidence, even if tests prove that the content itself was learned during the lessons (Kortland, 2001; Ratcliffe, 1997). In our view, that might be due to the interference of emotional and affective aspects of a topic.

A detailed discussion of the empirical data is given elsewhere (Menthe, 2006, 2012). For the purpose of this article, two findings are particularly interesting:

1. We only found a very small number of students changing their opinion toward tap water or mineral water during the series of lessons even in cases where the students' arguments were not supported by—or even were in conflict with—the

scientific evidence. Students, for example, kept claiming that "mineral water is cleaner" or "mineral water is more thoroughly controlled" or "mineral water is more healthy," as they did before the unit. The data were used to develop a typology that distinguished three types of student argumentation:

- Group a: students arguing mainly with ingredients and health aspects
- Group b: students arguing mainly with taste and lifestyle
- Group c: students arguing mainly with habits and routines

Especially students of the first type (a) were, to some extent, open to scientific evidence. As expected, most of the (very few) students (5 out of 80) who changed their opinion after the module were in group a (4 out of 5). In our interpretation, the reluctance to give up opinions bears stunning resemblance to the reluctance of students to change scientific beliefs and concepts, as discussed in the frameworks of conceptual change or growth (Chinn & Brewer, 1998; Menthe, 2012; Pintrich, 1999). Analyzing the reasons of the students who chose not to consider the scientific evidence showed that affective aspects (e.g., the image, attitudes, or routines) were more important for them than the scientific evidence.

2. The application of science knowledge depends largely on the context and its connection to beliefs and attitudes. An interview study on the same topic presented cases. For example, a female student explained her confusion after the series of lessons because she was convinced that lime in tap water was bad and harmful and was, therefore, a reason not to drink tap water. On the other hand, she now knew that mineral water contained minerals like calcium ions and that those minerals are useful nutrients. Though chemically equivalent, she did not connect the two terms ("lime" and "mineral"); and her negative attitudes and feelings toward lime impeded the combination of scientific evidence and her prior knowledge. It is likely that similar mechanisms happen in many students' minds on various topics. And often, the confusion is not even expressed by the students: scientific concepts are only applied in chemistry lessons and do not seem to touch daily-life beliefs.

More generally spoken, topics that are related to daily routines that contradict convictions and beliefs (as the statement "mineral water is healthier") or that raise strong emotions ("I don't feel comfortable drinking tap water") can restrict the application of school science knowledge. These findings are in coherence with assumptions of the conceptual change framework: students can react to unexpected information in various ways, and "entrenched beliefs" make it more likely that scientific evidence acquired in school is not applied and does not change one's thinking in everyday contexts (Chinn & Brewer, 1993).

Our findings are also in agreement with psychologists' discussions about the role of students' prior judgments for decision-making processes (e.g., Haidt, 2001; Kahneman, 2012; Strack & Deutsch, 2004). Advocators of the "two-process models" of information processing perceive decision making as always being influenced by quick, intuitive affects, based on attitudes and beliefs, in contrast to a rational choice view of decision making, where deciding is conceptualized as a process of deliberately (and unemotionally) calculating the advantages and disadvantages of possible options. According to dual-process models, decision making starts from an existing intuitive, often unconscious impulse. Rational consideration—e.g., due to new (science) knowledge—is at best a reevaluation of an existing opinion and is often just used to rationally justify a prior judgment ("post hoc justification," Haidt, 2001, p. 13). This is an important assumption for chemistry teaching that aims to foster scientific literacy as a requirement for democratic citizenship (Kolstø & Ratcliffe, 2007). It shows that for context-based chemistry education in general and for decision making in particular, the consideration of emotional aspects raised by chemistry content or chemistry-based socio-scientific issues is crucial. A way to address this problem is to reflect the students' judgments in class in order to demonstrate how chemistry knowledge, beliefs, and attitudes are tied together in decision-making processes. Alternatively, arguments from different interest groups such as industry, environmental actors, and others can be reflected and analyzed in the same way.

4 Conclusions and Outlook

In the first part of the paper, we explored frameworks of affective dimensions that are important for the design of teaching and learning approaches. In the second part, the application of such frameworks was outlined for the design of *Chemie im Kontext* modules. The qualitative study described in the third part points out a challenge of contextualization caused by affective variables: the conflict with everyday routines, attitudes, and beliefs that can arise in a specific context. In consequence, the intention of CBL to connect daily-life experiences with chemistry education at school might not be successful if the students themselves disconnect them again to avoid such conflicts. In the example of the choice of water types, scientific terms are simply not connected to the everyday context. Such aspects need further consideration and explicit reflection to encourage students to integrate school science knowledge into their daily lives.

In conclusion, there is still a huge demand for further research to examine the impact of context-based learning on motivation, stable personal interest, and attitudes toward science. The long-term effects of context-based teaching and learning especially have to be further investigated. Does CBL influence the affective memories that students hold of their science classes? How long do these effects last and how do they affect students' personal decisions and attitudes, for example, in subject choices, career choices, and attitudes toward science and technology? Does CBL efficiently support the development of stable personal interests of students in science?

A second important aspect is the relation of an increased motivation and cognitive learning outcomes. Does CBL support the development of mastery goal orientation? And does a mastery goal orientation in fact lead to a better performance in science in the short term and/or in the long run (remembrance after school science)?

A third aspect is the application of school science knowledge. Are the abovementioned examples of an interference of scientific content and daily-life beliefs replicable in other contexts? Is this an indication of a general problem of context-based learning approaches that needs to be addressed? When attitudes, beliefs, interests, and motivational aspects such as goal orientation are considered as preconditions and starting points for learning in a similar way as pre-knowledge and daily-life concepts, how do they interact or interfere with those cognitive variables? How can learning modules be successfully designed in a way that addresses both affective and cognitive preconditions in order to improve student understanding and to raise students' interest, motivation, and attitudes related to the content?

Future research can offer more answers to these questions!

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Gender Perspective on Affective Dimensions of Chemistry Learning

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Abstract Declining numbers of young people pursuing science-based areas of study and careers have often been reported in national documents around the globe. Students' positive attitudes toward science are found to be among the important factors contributing to their decisions to engage in science. Yet, science curricula focusing on the fundamentals of scientific knowledge, being transmitted to students, fail to enhance positive attitudes toward science, in general, and toward physical sciences, in particular. For complex reasons, girls, more likely than boys, tend to disengage with physical sciences and engage with certain fields such as biology, psychology, and the social sciences. Student attitudes toward learning science have been broadly addressed; however, studies concerning attitudes toward chemistry and attitude relation with gender, in particular, remain limited. The focus of this chapter is on research findings over a period of several decades regarding the impact of gender on student affect related with chemistry. The review uncovers mixed results, some studies reporting more positive attitudes for girls and vice versa. Grounded in feminist theories, this chapter also provides an analysis to understand the gender impact on affective dimensions in chemistry learning. Evidence suggests that conclusions drawn about student participation and affect in physical sciences may not hold true for chemistry. It is also suggested that an existentialist feminist theoretical perspective may be informative in accounting for the difference between the two genders regarding affect in chemistry and physics. Implications of the apparent less "masculine" image of chemistry for chemistry and science education are discussed.

1 Introduction

Science education worldwide and in advanced countries, in particular, has received increasing attention due to concerns of improving economic well-being and competitiveness which necessitate a proper supply of quality scientists and engineers.

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More recently, discussions have shifted focus on the need of engaging all students in science, regardless of their intended career choices, in order to build scientifically literate societies that critically approach scientific issues and knowledge. Contrary to the anticipations, in many countries around the globe, national reports and research documents highlight low interest or declining numbers of young people choosing to pursue careers in science. Despite the increasing enrollment in higher education in the USA, for instance, certain science and engineering fields (i.e., physical sciences) continue to receive lower attention from freshmen (National Science Board [NSB], 2012). On the other hand, a common alerting trend in European countries is that the more advanced a country is, the more negative attitudes its students have toward school science (Osborne & Dillon, 2008).

The picture is more worrisome when examined in light of gender. A vast body of research report females' disproportionate distribution in certain fields of science as compared to males. Women's uneven participation occurs in both education and career domains. According to the recent statistical data for 2009, in the USA, the majority of bachelor's degrees in physics, engineering, and computer sciences were earned by men (82 %, 82 %, and 81 %, respectively). Women obtained half or more of the bachelor's degrees in biological sciences (60 %), chemistry (50 %), psychology (77 %), agricultural sciences (51 %), and social sciences (54 %) (NSB, 2012). Similarly, women's participation rates in science and engineering occupations are lower than their participation share in the workforce overall. Women are employed in lower rates in certain areas such as mathematical/computer science (25 %) and engineering (12 %) and in higher rates in traditionally female occupations such as nursing (National Science Foundation [NSF], 2013). Across the 27 EU countries in 2009, less than one third of tertiary education graduates in mathematics, science, and engineering fields were women, which has been reported to be the case since 2000 (Eurostat, 2013a). Among European women occupied in science and technology, the vast majority are reported to work in the services sector as opposed to the manufacturing sector, a field closely related to engineering. In this sector, women constitute 29 % of the human resources (Eurostat, 2013b).

Some scholars argue that a large part of the problem appears to be rooted in school science, which starting from early years often fails to appeal to many students, particularly girls (Osborne & Dillon, 2008). Science curricula focusing on the fundamentals of scientific knowledge, being transmitted to students, fail to enhance positive attitudes toward science, in general, and toward physical sciences, in particular. Research suggests that students' interest in and positive attitudes toward science are among the important factors contributing to their decisions to engage in science. Furthermore, attitudes toward school science are viewed as having a stronger influence on decisions to engage in science than attitudes toward science in general. A better explanation of children and young people's decisions to engage or not in science comes from theories on the relation between attitude and behavior.

In their extensive review of the literature on attitudes to science, Osborne, Simon, and Collins (2003) draw attention to attitudes toward doing school science rather than attitudes toward science itself. Based on Ajzen and Fishbein's (1980) theory of reasoned action, it is argued that attitudes toward doing school science better predict the actual doing of science than do attitudes toward science. Osborne and colleagues emphasize that the perception of school science and the feelings about undertaking further actions in studying science are the most important factors in students' decisions of whether or not to continue pursuing post-secondary study of science. A number of studies in science education provide empirical evidence that beliefs about the consequences of pursuing science are important determinants of enrolling in science (i.e., Crawley & Black, 1992).

Recent developments focus to improve school science by making science experiences more meaningful for students. Among the new curricular orientations are project-based learning (PBL), inquiry-based science education, science-technology-society (STS), and context-based approaches. Being an initiative in chemistry education, the context-based approach provides a different route for learning chemistry concepts by situating learning in real-world contexts that relate to students' lives (King & Ritchie, 2012). King and Ritchie (2012) provide a detailed review of context-based approaches as implemented in five international programs: *Chemistry in Context* in the USA, *Salters* in the UK, *Industrial Science* in Israel, *Chemie im Kontext* in Germany, and *Chemistry in Practice* in The Netherlands. As highlighted by the researchers, context-based approach to teaching and learning chemistry is more than applying chemistry concepts to the real world; it is based on a need-to-know principle. Besides enhancing deeper understanding, context-based chemistry education in these programs is reported to improve students' affect such as interest in and attitudes toward chemistry.

Research in science and, particularly, in chemistry education has undoubtedly come a long way in the last several decades with many implications to impact teaching practices. Yet, as the recent statistics provided in the beginning of this chapter and the concerns about school science demonstrate, the anticipated levels of interest in and positive attitudes toward science have not been attained. Despite the implementation of research-based pedagogies like context-based chemistry teaching, improvements in students' affect have had limited scope. The following section provides a brief overview of the affective domain and a closer examination of attitudes toward science, in general, and chemistry, in particular, as related with gender.

2 Attitudes Toward Science and Chemistry: A Gender Perspective

2.1 What Is the Meaning of Attitude?

The aims of science education are concerned not only with students' cognition but also with students' "affect," a key term usually used as a synonym to "emotions" (Reiss, 2005). Furthermore, research has established that certain affective variables are influential in students' developing conceptual understanding over time (Nieswandt, 2007). While the objectives of education in the cognitive domain have been structured with relatively little difficulty, the efforts to clarify the desired outcomes in the affective domain have encountered challenges (Klopfer, 1976). This difficulty is partly due to the multiplicity of the theorizing of "affect" and, as Klopfer suggests, related with the uncertainty of what would be considered as related behavioral exhibitions.

In general, "affect" is used as an umbrella term for emotions, feelings, moods, and attitudes (Reiss, 2005). On the other hand, science educators consider interest, motivation, attitudes, beliefs, self-confidence, and self-efficacy as constructs of the affective domain (Alsop, 2003). Of these, attitudes toward science have been the particular focus of research in science education concerning affect (Alsop, 2005). Based on the earlier work of educational theorists, Nieswandt (2005) defines attitude as "a predisposition to respond positively or negatively to things, people, places or ideas" (pp. 41–42). As such, attitudes of students toward science involve students' predispositions to respond to science and scientists based on the views and images they develop as a result of relevant experiences (Ramsden, 1998).

2.2 Gender Research on Attitudes Toward Science

Despite the many advances in the understanding of science teaching and learning, it is still a widely encountered issue that females are less interested in and have less positive attitudes toward science in general as well as toward school science than males. According to the meta-analysis conducted by Weinburgh (1995), over the 21 years between 1970 and 1991, boys have consistently held a more positive attitude toward science than girls. In this meta-analysis, distinction between science and school science was not made, and given that the notion "attitudes toward school science" is relatively recent, it is possible to say that attitudes toward science in general were addressed. Though, a positive attitude was found to be more necessary for girls to succeed in science. More recent studies confirm this overall pattern; for instance, Brotman and Moore (2008) report in their meta-analysis that with few exceptions, many studies demonstrate girls' less positive attitudes toward science in general and lower participation in science courses than boys. The researchers also report that girls prefer biological sciences more than physical sciences, a trend similarly echoed by Vockell and Lobonc (1981) more than three decades ago. Archer et al. (2012) find that elementary children of both genders have positive views about science but that "boys are considerably more likely to be 'very keen' on science" (p. 982). In various studies, girls are reported to have different interests than boys in science-related topics. It is also reported that for complex reasons, girls, more likely than boys, tend to disengage with physical science learning and engage with certain fields such as biology, psychology, and the social sciences.

2.3 Gender Research on Attitudes Toward Chemistry

Numerous studies have been conducted on student attitudes toward learning science in general; however, studies concerning attitudes toward chemistry and attitude relations with gender, in particular, remain limited. Some studies tend to report results for physical sciences, a categorization that includes chemistry; but concerning student affect or participation rates, it appears that, for chemistry and physics, there are different patterns. Although limited in number, this chapter focuses on published research in the literature over a period of several decades regarding the impact of gender on chemistry attitudes or other affective variables. The majority of the studies are descriptive in nature, exploring whether there are differences in attitudes toward chemistry with respect to gender (i.e., Cheung, 2009; Hofstein, Ben-Zvi, & Samuel, 1977). A few investigate the way attitudes relate to achievement (i.e., Lewis, Shaw, Heitz, & Webster, 2009). One experimental study was conducted to understand the effect of using analogies in chemistry teaching on students' achievement and affect (Sarantopoulos & Tsaparlis, 2004). Following is an overview of these studies.

As a number of scholars in the field (Cheung, 2009; Hofstein & Mamlok-Naaman, 2011) emphasize, the literature provides mixed results concerning gender and attitudes toward chemistry. Over a period of nearly 40 years, some studies report more positive attitudes for girls and others report vice versa. The first research in the topic appears to be conducted by Hofstein et al. (1977) with Israeli high-school students (ages 16–18). The researchers found that girls had a more positive attitude toward chemistry and chemists than boys. The research results also suggested a more feminine image of chemistry as compared to physics, which explained the high enrollment rates of girls in chemistry courses. It is interesting that along with the feminine image of chemistry, physics was considered as more prestigious than chemistry with a superior social and economic image.

Another study that reported more positive attitudes for girls toward chemistry is a meta-analysis of research conducted with school-aged children between 1965 and 1981 over 20 countries (Steinkamp & Maehr, 1984). The analysis concludes that "girls' motivational orientations in biology, botany, and chemistry surpass those of boys, whereas boys' orientations are more positive than girls' in physical science and general science" (p. 48). The authors propose that the underlying reason for the differences in attitudes may lie in the fact that some science subjects such as physics are typically experienced by boys through informal learning activities out of school, whereas chemistry, for example, is learned mostly at school. The meta-analysis raises some concerns as to the conceptual and statistical weaknesses of the studies conducted and highlights the need to address the gender issues in a more straightforward manner.

Along with few other studies (i.e., Dhindsa & Chung, 1999; Shannon, Sleet, & Stern, 1982) that report girls enjoying chemistry more than boys, there is a body of research that provides contrasting results. According to studies conducted in Israel (Menis, 1983), in the USA (Menis, 1989), in Australia (Barnes, McInerney, &

Marsh, 2005), and in the UK (Harvey & Stables, 1986), all with high-school-level students, boys hold more positive attitudes toward chemistry than girls. Similarly, Salta and Tzougraki (2004) examined 11th grade Greek students' attitudes toward the difficulty, the interest, the usefulness of chemistry courses, and the importance of chemistry in the students' life. Although there were no differences between girls and boys on three of the subscales (interest, usefulness, importance), the results suggested that girls had more negative attitudes regarding the difficulty of chemistry courses.

One of the criticisms for the studies producing mixed results was the lack of attention to a possible grade level and gender interaction (Cheung, 2009). Cheung explored secondary 4–7 students' (ages 16–19) attitudes toward chemistry lessons in Hong Kong and examined the interaction effect, in particular. The researcher used an attitude scale consisting of four subscales: liking for chemistry theory lessons, liking for chemistry laboratory work, evaluative beliefs about school chemistry, and behavioral tendencies to learn chemistry. Cheung's findings related with gender varied across grade levels. For instance, the results suggested that males liked chemistry theory lessons more than females only in secondary grades 4 and 5. In upper grades, there was no attitudinal difference with regard to theory lessons. Females' attitudes improved over grades 4–6 and leveled off during grade 7. Contrary to the common trends in physical sciences in general (including chemistry), in Cheung's study, males' attitudes toward chemistry laboratory work declined from junior to senior grades, while females' attitudes did not change.

Other researchers examined the interaction of gender with variables such as stream (gifted and non-gifted groups), as related with student perceptions of laboratory environment and teachers (Lang, Wong, & Fraser, 2005), or the role of the interaction of gender and achievement level in attitudes toward chemistry (Brandriet, Xu, Bretz, & Lewis, 2011). In Lang et al.'s (2005) study, differences were found between non-gifted girls' and boys' perceptions of the degree to which laboratory activities were open-ended. Non-gifted girls perceived the laboratory environment as being more open-ended, while gifted girls and boys perceived it in a similar way. Data analyzed without taking into consideration the stream effect showed no differences between boys and girls on the same variable. In this study, gender analysis was not conducted regarding students' attitudes toward chemistry.

When examined for students of different achievement levels, there is evidence that gender is related with attitudes in different ways (Brandriet et al., 2011). Brandriet and colleagues administered pre- and posttests to college students enrolled in general chemistry courses. They measured attitudes toward chemistry and found that students who were identified as "at risk" showed gender differences. The "at-risk" students in the particular institution were identified as being "at risk" for attrition from general chemistry based on an initial analysis of the correlation between chemistry grades and scores on the university mathematics placement exam. Girls in the "at-risk" student group exhibited less positive attitudes, while boys had more positive attitudes. Even after a shared chemistry learning experience in mixed-gender groups, girls' attitudes toward chemistry were significantly less favorable than boys'. The researchers found that in the high-achieving group, the attitude difference was not statistically significant.

2.4 Relationship Between Affect and Cognition

A considerable amount of research in science education has examined the way attitudinal and motivational factors affect cognitive learning, suggesting meaningful relationships between the two (Koballa & Glynn, 2007). Conducted in this vein, some of the studies reviewed in this chapter establish a relationship between affective variables and student achievement in chemistry. For instance, Lewis et al. (2009) found that affect plays a role even after controlling for cognition. The study showed that after controlling for SAT scores, self-concept continued to play a role in student performance as measured by the ACS exam in the US. Preliminary results in this study suggested differences in the role of self-concept for male and female students' achievement, but these results were inconclusive.

In another study that explored the effect of both cognitive and noncognitive variables on organic chemistry achievement, students' general chemistry grades and ACT scores were found to be the strongest predictors of organic chemistry achievement (Turner & Lindsay, 2003). Interestingly, for females, none of the noncognitive variables were found as being related to organic chemistry achievement. On the other hand, for males, anxiety and confidence were found to be moderately correlated. Finding no relationship between noncognitive variables and achievement for females, the researchers call for further studies of variables that could be playing a role in females' low performance in advanced courses such as organic chemistry.

Sarantopoulos and Tsaparlis (2004), on the other hand, consider attitudes as outcomes of chemistry teaching along with achievement. The researchers found that using analogies in chemistry teaching helped to improve students' views toward chemistry as well as their achievement. In their study, students at the concrete developmental level were found to benefit more from the analogies and to develop more positive opinions. In the analyses including the gender variable, no gender differences were detected in terms of achievement or chemistry views.

As demonstrated in the overview of the published literature on attitudes toward chemistry and attitude relations with gender, there are varied and sometimes contradictory results. Hofstein and Mamlok-Naaman (2011) identify type of measure, contextual differences reflected in the chemistry curricula, different grades, and teaching strategies and methods as possibly being among the reasons leading to such different results. Despite the dissimilarities from the studies reviewed, it appears that chemistry as a physical science is relatively less likely to generate differential gender effects than physics, for example. A vast amount of research report lower interest and participation rates of high-school girls in advanced level physics classes than boys (i.e., Häussler & Hoffmann, 2002; Zohar & Bronshtein, 2005). For instance, Häussler and Hoffmann (2002) indicate that in Germany only about 10 % of girls opt for physics at the upper secondary level. Similar rates are reported for many other countries. More than three decades ago in their work with high-school students, Hofstein et al. (1977) revealed a more masculine image of physics than chemistry. According to Zohar and Bronshtein (2005), physics is a subject that girls identify as belonging to a male domain due to various socialization processes. For example, boys are more exposed to physics-oriented toys and games such as bike ride or constructing electrical circuits and mechanical sets than girls from early ages. It is a widely encountered issue that many girls think physics is the most demanding science subject in which boys have natural ability. Girls also view physics as war oriented and destructive. The male image of physics that girls develop at early ages is reinforced by family members, friends, books, media, and later by teachers' and male classmates' attitudes and behaviors.

Not all but many studies, including Steinkamp and Maehr's (1984) extensive meta-analysis, conducted in the different parts of the world reveal more positive attitudes toward chemistry for girls. Also, in higher secondary education grades and in gifted or high-achieving student groups, females and males do not exhibit different affect related to chemistry (Brandriet et al., 2011; Cheung, 2009). In advanced courses such as organic chemistry, previous achievement, again, appears to be a stronger predictor for females' success than the explored noncognitive variables.

The next section is concerned with feminist theories and their use as a framework to understand the gender differences that do exist in affect. This section involves three parts. Following the section introduction, in the first part, the historical context giving birth to contemporary feminist theories and the tenets of essentialist and existentialist feminist thought are introduced. The second part uses the historical context and feminist theory framework to offer a broader account for the gender differences observed in the science fields. The third part extends this account to the field of chemistry and provides an analysis that can be used to recognize the differences between chemistry and other physical science subjects from a gender perspective.

3 Feminist Theories' Insight into the Gender Differences

The patterns of uneven participation of the two genders in physical sciences and life sciences are a likely consequence of students' affect related to these fields. In her study comparing gender differences in life, physical, and earth science classes, Britner (2008) reported higher levels of science anxiety for girls than for boys in the physical sciences fields at the high-school level. On the other hand, in the Earth and environmental sciences, girls demonstrated higher achievement and had higher self-efficacy than did boys. Britner also found that there were different sources for girls' and boys' self-efficacy in these domains of science. For boys, the source of self-efficacy in both physical and life sciences was their mastery experiences or previous performance. On the other hand, variables identified as social persuasions, physiological states, and vicarious experiences had an important contribution to girls' self-efficacy in these fields. Britner draws attention to the sources of self-efficacy that are important for girls. Social persuasion, or "the verbal and nonverbal judgments provided by others" (p. 4), Britner argues, is a key factor for self-efficacy in life sciences for girls, most likely because these fields have traditionally attracted more women than men in both education and workforce. Life sciences are viewed by most societal actors as more appropriate for girls than for boys, a tendency that could be better understood when approached by a feminist theory lens.

3.1 Historical Accounts, Essentialist and Existentialist Feminism

Of the many feminist theories, essentialist feminism focuses on gender differences based on biology (Rosser, 1997). Gender differences are expressed in terms of visuospatial and verbal ability, aggression and other behavior, and other physical and mental traits based on prenatal or pubertal hormone exposure. These difference claims are likely to have originated from the work of the eighteenth- and nineteenth-century sexist scientists, who in turn were inspired by a tradition of ancient thought. The following is a short review of historical accounts leading to women's subordinate status that has been sustained over many centuries.

According to ancient scientists, "temperament (sexual or otherwise)" was determined by four elements (called humors), which at the same time were the four fundamental elements composing the universe: air (which is dry), water (which is wet), fire (which is hot), and earth (which is cold). In Aristotelian/Galenic view, women lacked heat compared to men; therefore, they were not able to expel their reproductive organs, as men had done. Since hot and dry things were considered as superior to those cold and wet, women were thought as "incomplete/imperfect" men. In later years, going against Aristotle, Descartes indicated that reason, or the ability to use logic, was the same in all humans. For that reason, he was considered as a defender of women. According to Descartes, the only difference between sexes was their reproductive organs. Mind and body were separate; thus, the difference in the body would not generate a difference in the mind, or the reasoning capability (Schiebinger, 1989).

In the late eighteenth century, sexual differences were no longer seen as remaining only in the reproductive organs. By the 1790s, European anatomists—almost all white men—pointed to the differences between female and male body, arguing that men were distinct in their physical and intellectual strength and women were distinct in their motherhood skills. However, this difference was not solely a difference; it was also arranged hierarchically, in favor of men.

The anatomists of the eighteenth century looked at the female and male skeletons to justify their theses; in other words, "scientific theories of difference were used to justify women's exclusion from higher education and public life" (Weedon, 2000, p. 7). These scientists considered the skeleton as the most fundamental element in the human body. Monro, a professor of anatomy, was among the first to look at a female skeleton. He described female bones as incomplete, thus causing the female body to be incomplete and deviant, “measured” against the male body which was *the standard*. According to Schiebinger (1989), Thiroux d’Arconville, another anatomist (and a woman), drew the most “sexist” skeleton of a female body. The skull of the female skeleton she drew was smaller in proportion to the body than a male’s, the pelvic area was very broad, and the ribs were very narrow. The “feminine” details in her and other anatomists’ drawings were “knotted” to support social ideals of femininity and masculinity. In addition, according to Trecker (2001), evolutionists of the nineteenth century claimed that women’s development had stopped at a lower stage of evolution, because of their sexual differences. In other words, in the nineteenth century, starting from biological sex and claiming objectivity, these scientists defined masculinity and femininity and claimed that these, as well as race, determined social worth (Schiebinger, 1989; Trecker, 2001).

By restricting women’s participation in the public sphere, in the seventeenth through nineteenth centuries, European men (and in some exceptional cases, European women like Thiroux d’Arconville) ensured the “masculinity” of science fields and made (easy) sexist arguments without the input of women (Schiebinger, 1989). Doing science was “forbidden” to women and labeled “unfeminine,” thus pushing women to the “margins” of scientific knowledge (Eisenhart & Finkel, 1998). Ironically, before science had become the center of social power and intellectual focus to replace theological and philosophical studies, theology and philosophy were the disciplines considered “unfeminine” and inappropriate for women. When science itself was heretical and had a lower prestige compared with classical knowledge, men encouraged women to be active participants in science. Women wrote science books, textbooks, and scientific articles for journals. Midwifery and medicine were among the sciences mainly pursued by women, but that only lasted until their recognition as scientific professions in the industrial era (Schiebinger, 1989; Trecker, 2001).

An implicit process called the “reproduction of subordinate status” (Eisenhart & Finkel, 1998) has served to keep women subordinate to men by means of culturally encouraging women to value and pursue “feminine” behaviors and fields of study. Power relations had been preserved. The early ideological constructions and formulations of science originating from ancient prejudices “stated in the most modern and approved words” (Trecker, 2001, p. 96) have served as barriers to keep women away from the science, mathematics, and engineering fields until the present day.

The historical context gave birth to the theorizing of various contemporary feminist perspectives. Since the first-wave feminist movement (sameness feminism) in the eighteenth century, various feminist perspectives led to the analysis and different explanations of women’s subordinate status. The first-wave feminist movement was followed by the second (difference feminism) and third waves, each building on one another and appropriating the previous. All of them were political in nature, and the politics of feminism challenged the existing power relationships between men and women in society (Weedon, 1997).

The main strand of the first-wave feminist movement was liberal feminism. A general definition of liberal feminism is the belief that society bars women from participating in science and other scientific organizations with external political and social forces (Barton, 1998; Howes, 2002; Schiebinger, 1989). The main discriminatory idea that liberal feminists refused was the argument that women lacked rationality and that they were not qualified for citizenship or other domains than the private. Liberal feminists seek no specific privileges for women but require the removal of the "barriers" and fixing the social and political forces that keep women out (Howes, 2002; Rosser, 1997). According to liberal feminists, everyone should receive *equal* opportunities without discrimination on the basis of sex (Rosser, 1997). The goal is to have s*ameness* with men, and equality is essential (Scantlebury, 2002; Weedon, 2000). One of the problems of assuming sameness with men and requiring no change in patriarchal structure was that women were expected—and "fixed"—to be like men (i.e., with no off time to have children) (Scantlebury, 2002; Schiebinger, 1989).

The second wave, difference feminism, stresses that women and men are different, and women should be given proper provision for the differing needs that they may have. Two strands of difference feminism, essentialist and existentialist feminism, view women's differences as originating from different sources. The nineteenth-century essentialist feminists propose that women are inferior in some physical and mental aspects while superior in other aspects, such as morals. Some essentialist feminists basically accept the ideas of men essentialist scientists, beginning from Aristotle, which imply that women cannot do science as well as men and that they are more suitable for "domestic" work (Schiebinger, 1989).

Others celebrate women's difference and argue that women's nature is not something to be replaced but to be maintained, for the sake of both women and society (Tobias, 1997). In this case, there is a denial of hierarchies (superiority vs. inferiority) in terms of some personal characteristics proposed by essentialists. Moreover, some essentialists claim the virtue of some natural traits specific to women and believe in their being more humane. For example, Gilligan's (1982) research on women's moral development and understanding of justice implies that "in the different voice of women lies the truth of an ethic of care, the tie between relationship and responsibility, and the origins of aggression in the failure of connection" (p. 173). Belenky, Clinchy, Goldberger, and Tarule (1986) also stress the importance of *connection* and its value in "women's ways of knowing." Both studies point to the *empathy* women enact while learning or relating to others, unlike men. Both of them imply innate differences that women and men have in terms of moral reasoning and learning.

In contrast to essentialist feminists, existentialists suggest that women's "otherness" is caused by society's interpretation of biological differences, and not by the biological differences themselves. The assumed different learning styles and abilities (such as visuospatial abilities) are based on differential treatment of boys and girls, especially at young ages (i.e., playing with dolls vs. playing video games).

Girls are then implicitly forced to behave like "girls" and to act feminine. The major distinction with the essentialist feminist perspective is the assertion that the differences between women and men spring from their upbringing and not from their nature (e.g., different hormones) (Rosser, 1997).

The major third-wave feminist strand, postmodernist feminism, rejects the idea that as claimed, the various feminisms would address all women's needs. As Rosser (1997) states, "postmodernism dissolves the universal subject, and postmodern feminism dissolves the possibility that women may speak in a unified voice or that they may be addressed universally" (p. 99), because factors such as race, class, nationality, and sexual orientation make women different from each other. Poststructuralist feminists, on the other hand, "have sought to deconstruct existing metanarratives and to develop new theoretical approaches which insist on historical and geographical specificity and no longer claim universal status" (Weedon, 1997, p. 172). Instead of making generalizations while addressing women's oppression, poststructuralist feminists argue for attending to women's differences both within and between historical periods or cultures. They deny a fixed (gendered) "self" and view this self as being constructed through language-articulated experience. According to Barton (1998), third-wave feminism demands "self-reflexivity," which is about being aware of one's own *positionality* (personal history, biography, gender, class, ethnicity, etc., in a specific context and history) while making sense of the world or taking certain actions.

3.2 How Women Remain on the Margins of Science

The fact that women are less likely to enter science, mathematics, and engineering majors at the college level than men is very closely related with women's historically subordinated status. In a sense, women are "suffering" prolonged effects of alienation from these fields since ancient times. As discussed before, the forces that keep women away from these disciplines originate from the nineteenth-century (and earlier) *conservative* scientists' insistent work of justifying cultural expectations of women and the sexual division of labor.

The "masculine" structure of science as a discipline (Lederman, 2003), established in the past by not accepting women as participants, has had its effects as an invisible "repelling" force from these fields (Nichols, Gilmer, Thompson, & Davis, 1998). Furthermore, with the rise of the theory of complementarity in the late eighteenth century, certain natural sciences were thought as "more appropriate" for women, and one of them was botany (Schiebinger, 1989). Societal expectations can be very powerful in shaping personal orientations. More recently, researchers find that girls hold more positive attitudes toward biology than any other natural science (Brotman & Moore, 2008; Vockell & Lobonc, 1981; Weinburgh, 1995). A large-scale survey study conducted with more than 2,500 scientists in research universities in the USA reports that most of the reasons for the differences in the distribution of women in biology and physics are stated as being limited mentoring for women in physics, discrimination, and women's preference for biology. A smaller percentage of respondents believe in women's natural ability in biology than in physics (Ecklund, Lincoln, & Tansey, 2012).

An existentialist perspective would suggest that girls' more negative attitudes toward physical sciences and engineering are shaped by previous social and familial experiences, societal expectations, as well as educational experiences, beginning from elementary school. Traditional factors, such as family background, parent and even teacher attitudes toward girls and science, and what they think girls' roles in the society are compared with those of boys', have directly or indirectly influenced girls' interest in mathematics- and science-related fields (Department of Education and Science [DES], 1975; Kahle & Lakes, 1983). For example, in most occasions, parents dress their daughters in pink and their sons in blue; they give their daughters Barbie dolls to play and their sons toy cars and construction sites. Often these parents encourage their sons and welcome them to take things apart, while they may blame their daughters for the same behavior. Among other factors are gender-biased illustrations in high-school science textbooks (favoring men) (Bazler & Simonis, 1990) and the "feminine perspective" (Gilligan, 1982) of relationships and learning that is overlooked by teachers (Peltz, 1990) or faculty members at the college level.

The outcome is that many young women become unwilling to pursue careers in science, mathematics, and engineering during middle school or earlier. Kahle and Lakes (1983) point to the fewer number of science experiences for girls than for boys, which include "science observations, instrument skills, field trips, experimental tasks, and extracurricular activities" (p. 136). The gap between genders continues to widen following primary and middle school years. By age nine, although expressing interest, girls experience less science activities than boys; this continues through ages 13 and 17 and results in girls taking fewer number of science courses in high school. This in turn results in women's underparticipation in college-level science, mathematics, and engineering majors (Bohonak, 1995). Nevertheless, Peng and Jaffe (1979) report that taking enough number of mathematics and science courses in high school is a very strong predictor of entering "male-dominated" fields, both for men and women.

According to Kahle and Lakes, teacher attitudes toward gendered issues, such as expectations geared toward a perspective that boys can do "more science" (and "better") than girls, can be also very influential in girls' developing less positive attitudes. Kahle and Lakes (1983) relate such an attitude to the fact that most elementary teachers are women who themselves have a low confidence in teaching science and thus may represent "bad" role models by projecting their own scientific attitudes onto girls. When boys and girls are paired for performing scientific experiments, teachers may also allow boys do most of the work and girls watch. Jones et al. (2000) also report that boys are significantly more likely to play and tinker with science materials and tools, whereas girls are more likely to touch them and to follow the teacher's directions in the science activities.

To sum up, starting from middle school or earlier, girls develop a very restricted view of science as dealing with medicine, pharmacology, or nutrition and do not picture themselves as future scientists (Kahle & Lakes, 1983; Peltz, 1990). Furthermore, girls and women see physical sciences as unrelated to their feminine identity. Schiebinger (2001) suggests that physical sciences seem "cold" to women for a number of reasons. Physical sciences (1) have a cultural image of being "hard" (and humanities and social sciences of being "soft"), (2) have an aggressive culture, (3) tie historically to the military, (4) include extensive use of abstract mathematics, (5) have an image of being part of "big science," and (6) require large and capital-intensive equipment. This distorted view leads girls to arrive at conclusions such as science being "masculine," which in turn discourages the girls from doing *it*. It is established by different scholars that girls (and boys) view biological/life sciences as being less masculine than physical sciences (Farenga & Joyce, 1999; Jones, Howe, & Rua, 2000; Vockell & Lobonc, 1981).

3.3 Affect in Chemistry in Light of Feminist Accounts

So, where is chemistry positioned within the feminist accounts given girls' relatively more positive attitudes at secondary level as compared with boys' and higher participation rates at college? Although a generalization such as this would be overlooking the variations due to methodological elements such as type of measure as well as contextual differences in each inquiry, the review of research on attitudes and other affective dimensions in chemistry allows for a consideration of chemistry in a different position as a physical science. Chemistry as a field of science appears to be less likely to generate differential gender effects than its categorical counterpart, physics. There is considerable evidence that for most of the time, secondary school girls and boys possess comparable attitudes toward chemistry, if girls' attitudes do not surpass those of boys. In addition, it is common that women at college pursue majors in chemistry in a much higher rate than in physics (e.g., in 2009, in the USA, women obtained 50 % of the chemistry and 18 % of the physics bachelor's degrees).

Previous research results suggesting that girls (and boys) view biological/life sciences as being less masculine than physical sciences need to be approached with caution. It is clear that chemistry and physics, both physical sciences, do not evoke the same attitudinal effects in students. Chemistry appears to have a more feminine image than that of physics, which was suggested by Hofstein et al. (1977) for Israeli students more than three decades ago. Schiebinger's (2001) argument of physical sciences seeming "cold" to women could only be partially valid in this context.

Attribution of a feminine image to chemistry implies that other disciplines of science could be considered as more "masculine" (i.e., physics). As discussed earlier in the chapter, in the seventeenth through nineteenth centuries, the "masculinity" of the scientific fields had been ensured by restricting women's participation in higher education and public life. Masculinity and femininity were defined and redefined in light of early "scientific" and yet ideological constructions based on ancient prejudices. These "scientific" explanations justified cultural expectations from women and the sexual division of labor and assigned certain natural sciences, such as botany, to them as "more appropriate" fields. The "hard-" core sciences with a higher social power and greater intellectual focus were considered as more appropriate for men. Hofstein et al. (1977) provides evidence on this by finding that the students in their sample considered physics as more prestigious than chemistry with a superior social and economic image. The same students perceived chemistry as being more feminine.

Given that both chemistry and physics are considered in the physical sciences realm and that there is interrelated content, one would expect that the needed learning styles and abilities (such as visuospatial abilities) for succeeding in physics and chemistry do not differ much. Most essentialist feminists view these abilities as primarily masculine characteristics, inherent to the biology of men. Thus, essentialist feminism would consider both chemistry and physics as "unfeminine" fields, relating to men, while from the research results presented in this chapter, it appears that this may not be actually the case. A more adequate approach would be that perceptions of masculinity and femininity of physics and chemistry develop as social constructions, as informed by an existentialist feminist point of view. From this perspective, the assumed differences in learning styles and abilities are largely due to differential upbringing of boys and girls, particularly at young ages.

A vast amount of research demonstrate that there are different experiences available to young boys and girls. For instance, Kahle and Lakes (1983) highlight that by age 13, only 35.4 % of girls had tried to fix something electrical and only 37.1 % had tried to fix something mechanical, compared with 68.4 % and 79.3 % of boys, respectively. More importantly, parental and teacher attitudes play an essential role in encouraging boys to take things apart and girls not to do so. Especially noteworthy is the nature of these experiences being physics oriented. In a similar manner, Steinkamp and Maehr (1984) suspect that the differences in attitudes of boys and girls may be due to some science subjects such as physics being experienced by boys through informal science activities outside school, whereas chemistry is learned mostly at school.

Societal expectations as related to exercising an "appropriate" or "inappropriate" domain of science, or the existence or nonexistence of role models, all can be very powerful implicit messages that are relayed to girls and young women at early stages of their identity development. Britner (2008) names these messages as "social persuasion" and draws particular attention to the results of her study that in life sciences social persuasion appeared as the most effective factor contributing to girls' self-efficacy in these fields. Life sciences are well known for traditionally attracting more women than men in both education and workforce. In a similar manner, girls' having relatively more positive attitudes toward chemistry than physics may be related to the fact that women scientists are more visible in chemistry than in physics school curricula (i.e., Marie Curie is well known for her pioneering work in radioactivity and appears in many chemistry textbooks).

4 Concluding Remarks

Findings in the chemistry education literature about students' affect related with chemistry provide evidence that as a field of physical science, chemistry has a less "masculine" image than physics. As a consequence, it is encouraging for chemistry educators that in many studies, girls' and boys' affect related to chemistry is found to be comparable and, in others, to be more positive in favor of girls. Though, research concerning the impact of gender on chemistry attitudes or on other affective variables remains very limited as compared to studies addressing science, in general, and physical sciences, in particular. This underlines the need for further research in the particular area of chemistry with respect to gender and affect. Furthermore, researchers need to consider variables such as ethnicity and socio-economic status that may mediate any gender impact on chemistry affect so as to avoid producing misleading results (Scantlebury, 2012).

This chapter suggests that conclusions drawn about student participation and affect in physical sciences may not hold true for chemistry. For instance, in Britner's (2008) study, girls report higher science anxiety in physical sciences than boys; however, the level of science anxiety may vary across the fields of chemistry and physics. Similarly, that social persuasion is the major contributor to girls' self-efficacy in life sciences and not in physical sciences does not provide much information about its effect in chemistry. Although widely practiced in research and reports, the use of "physical sciences" in reference to both physics and chemistry could be misleading in interpreting information, especially given that chemistry is viewed in a different way by many students.

The overall difference between genders regarding affect in chemistry and physics gains more meaning when looked at from an existentialist feminist theoretical perspective. The distinction among certain natural sciences as "feminine" and "masculine" has traditionally persisted over centuries and is likely to continue being influential. If girls and boys are raised in different ways, encouraged by their parents, teachers, and society at large by explicit and more implicit means to behave in particular ways, then a focus on these means is both necessary and urgent.

Measures need to be taken and carefully planned in order to enhance students' affect related with chemistry and their participation in the chemistry field. Furthermore, chemistry educators, curriculum developers, and other stakeholders may take advantage of the less masculine image of chemistry in enhancing girls' attitudes and participation in science. Both students and parents may be exposed to women chemists' work and personal lives to enhance young people's perceptions of scientists and perceptions of relevance to own life (Barutcuoğlu, Kahveci, & Şeker, 2011). In addition, the goals of scientific literacy may be more readily pursued by using chemistry subjects as means. Context-based chemistry may prove to be a useful means in achieving this aim. For instance, socially relevant topics in chemistry such as ozone depletion or harmful household cleaners may be used as venture points in chemistry lessons to practice informed decision making as well as to learn meaningful chemistry concepts.

Various other strategies may be developed, such as exposing high-school girls to vicarious experiences (Britner, 2008) in chemistry or involving role models and providing academic assistance at the college level (Kahveci, Southerland, & Gilmer, 2008). Designing more extracurricular and informal learning opportunities at both primary and secondary levels that focus on chemical aspects of everyday life or enhancing personal relevance by introducing chemistry subjects via topics stereotypically perceived as feminine and masculine may also be useful (Kerger, Martin, & Brunner, 2011).

Finally, embracing a broader gender perspective on the affective dimensions of chemistry learning and recognizing the variations among the physical science subjects in terms of affect require an existentialist feminist theoretical lens. As well, understanding the interaction between gender and affect in chemistry is of utmost importance in ensuring that chemistry is appealing to students of both genders. Likewise, it is important that scientific literacy could be broadly addressed over chemistry subjects and that no talents are lost in this physical science.

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Intuitions About Science, Technology, and Nature: A Fruitful Approach to Understand Judgments About Socio-Scientific Issues

Arne Dittmer and Ulrich Gebhard

Abstract According to the social-intuitionist model of moral judgment, this chapter highlights the significance of intuitive beliefs concerning socio-scientific issues. Using the example of genetic engineering, an approach from the field of biology education is presented as a theoretical frame for a better understanding of intuitive judgments. Teaching about socio-scientific issues in chemistry education is not only an issue if ethically relevant topics are explicit subjects of teaching but also if contents are ethically connoted and are imparted into science classes in a supposedly unbiased manner. The social-intuitionist model of moral judgment allows a deeper understanding of decision-making processes, which are based on culturally embedded beliefs about a science-based world or the meaning of nature. Those ethically relevant and almost implicit beliefs are here called "everyday myths." Such beliefs are part of the worldview and self-understanding of students and have effects on their decision making about socio-scientific issues. Knowledge about the intuitive dimension of ethical judgments should support a sensitive attitude of teachers toward students and toward the cultural range of science.

Keywords Decision-making processes • Intuitive judgments • Social intuitionism • Everyday myths

1 Socio-Scientific Issues: Challenges for Chemistry Education

The encouragement of students' ethical decision-making competence is among the aims of scientific literacy and provides a challenge for science teachers (Driver, Newton, & Osborne, 2000; Ratcliffe & Grace, 2003). It is a challenging task partly

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because it requires a variety of competences that go beyond the borders of scientific disciplines and the traditional school science education. Dealing with ethical problems demands complex context knowledge, an open-minded teacher, tolerance of ambiguity (e.g., because of uncertain evidence or controversial values), and social and communicative competences.

It is important to prepare students to deal with the broad field of socio-scientific issues related to the curriculum of chemistry classes (Fensham, 2004; Zeidler, 2003). Also of importance here is to qualify chemistry teachers for the challenge, so they are able to integrate socio-scientific issues in their daily work. Since ethical or philosophical reflections are not part of the curriculum of the science teacher education, it will be difficult to incorporate socio-scientific issues into science classes. Because of the differences between humanities and sciences (see Snow, 1959), science teachers feel insecure about their abilities to teach outside their discipline in order to foster ethical decision-making competence without the necessary qualifications (see Bauer, 1990; Hofstein, Eilks, & Bybee, 2010).

This chapter addresses the complexity and cultural embedment of socio-scientific issues and opposes a rationalistically constricted understanding of decision-making processes. According to the social-intuitionist model of moral judgment from Jonathan Haidt (2001) and in favor of a subject-orientated understanding of learning processes, the intuitive part of decision-making processes is presented in the following remarks. The social-intuitionist perspective will be specified by the didactical concept and research program "everyday myths" (Gebhard, 1999, 2007). According to the book *Mythologies* from Roland Barthes (1957), we understand "everyday myths" as ethically relevant beliefs, which founded on culturally imparted ideas about mankind and world and which influenced considerations about ethically relevant contents. This approach takes into account that an intuitive judgment does not only take place when explicitly addressing ethical matters in science class. It similarly occurs in ordinary science education when scientific topics are ethically connoted and evokes corresponding associations. Students evaluate science even if science teachers don't talk about social-scientific issues. These evaluations often run in the background of science education, and they don't have to be founded on rational arguments from the field of technology impact assessment. Our visions on science are already embedded in a broader cultural context.

Growing up in our culture means acquiring a strongly scientifically influenced understanding of oneself and the surrounding world. Science influences our ways to see the world (see Carvalho, 2006; Lewontin, Rose, & Kamin, 1984). In a science-based technological world, the internalization of scientific concepts starts with early childhood socialization. Parents, educators, and the media convey this view of a scientifically supported and secularized society when talking to children about the significance of adequate nutrition, the mechanism of nuclear fission, the relation between minds and brains, or the distinction between natural and artificial objects. And the scientific worldviews interact with religious, spiritual, or other approaches to the world. In this regard the ethical dimension of sciences and the related visions of mankind, technology, and nature provide an essential and not to be ignored background of science education.

Decision-making processes also take place in the background. The philosopher R.M. Hare distinguishes between the intuitive morality, determining everyday life, and the reflective morality, acting in which one abandons the habits of daily life to face ethical questions with distance (Hare, 1981). In this regard, socio-scientific issues are of equal importance in the background as well as in the foreground. In the foreground they can become an explicit topic of interest in, for instance, addressing the public discussion about technological impact assessment in science classes (Hodson, 2003). Simultaneously, these aspects operate implicitly in the background when simply teaching the molecular basics of genetic engineering without explicitly going into the discussion about socio-scientific issues. In that way, science education can impart ideas of scientific progress and at the same time evoke intuitions about the limits of legitimate research.

2 Decision-Making Processes from a Psychological Point of View: Intuitive and Reflective Thinking

As early as 100 years ago, Freud introduced the distinction of conscious and unconscious processes by psychoanalysis. According to Freud, the irresolvable interlocking of both areas constitutes the basic conditions of human psychic life. Reflection and perception of the outside world therefore always bear traces of unconscious processes:

> "The unconscious must [...] be accepted as the general basis for psychic life. The unconscious is the bigger circle enclosing the smaller one of the conscious; everything conscious has an unconscious pre-stage, while the unconscious stays at this stage and can nevertheless demand the overall quality of a psychological achievement. The unconscious is the actually real psychic, from its inner nature so unknown to us like the real outside world and equally incomplete, provided to us by the data of the consciousness like the outside world by the data of our sense organs" (Freud, 1900/1972, p. 617, translated by the authors).

The central keystone of the psychoanalytical view is the supposition of an unconscious, which conditions our behavior, emotions, and thinking far more than we are aware of. This implicational relation between consciousness and unconscious, between rational and irrational processes, between inner fantasies, latent structures of meaning, and outer conditions is taken up by modern psychology, which establishes its empirical foundation.

Perception itself is not a process of a neutral description of the environment but a selective translation of sense data regarding preexisting and not necessarily conscious memories (Anderson, 1983). The activation of associative nodes can be about factual information as well as topics that are set in context for other reasons (e.g., similarity or experience). Based on this, intuitions are understood as unconscious cognitions whose genesis remains hidden because only the result of thinking

Table 1 Intuitive and reflective thinking processes (Haidt, 2001)

The intuitive system	The reflective system
Fast and effortless	Slow and arduous
Process is unintentional and proceeds automatically	Process is intentional and controllable
Process is not accessible; only results become conscious	Process is consciously accessible (and regarding its logic) testable
Does not need attention capacities	Needs attention capacities which are limited
Parallel distributed processing	Serial processing
Comparison of patterns; thinking is metaphorical and holistic	Processing of symbols; thinking is truth seeking and analytical
Context dependent	Context independent

processes can become conscious. In drawing on psychoanalysis, Epstein (1994) describes the current interest of the empirical psychology in intuitions as a renaissance of the unconscious. In social psychology, unconscious thinking processes become, once more, an object of research under the two-process models. Analogous to distinguishing conscious and unconscious processes in psychoanalysis, social psychologists also distinguish two modes of processing of the cognitive system: controlled (reflective) and associative (intuitive) thinking processes (Evans, 2007; Schneider & Shiffrin, 1977). The shared characteristic of the different two-process models is that they describe a thinking mode in which information is processed associatively in the memory simultaneously with our perception (Smith & DeCoster, 2000). This obligatory thinking process is, on the other hand, contrasted with a coping process that is based on the application of symbolically represented rules which can be reconstructed with language and logic (Table 1).

In school education we foster the reflective way, when we analyze ethical arguments. The reflective mode can be applied in a facultative manner when sufficient situational motivation and intellectual capacity are available. Strack and Deutsch (2004) distinguish in their two-process model the "reflective system" from the "impulsive system." In the "impulsive system," thinking processes proceed impulsively along with associated memories and influence immediately our motivational orientation.

And impulsive respectively intuitive thinking plays also a role in rationale affairs like technology assessment. The human memory does not distinguish between ethically relevant and irrelevant contents. With the perception of a situation immediately available, memory contents are activated, leading to intuitive judgment. That way, the topic of genetic engineering, for example, can immediately evoke the idea of the untouchability of nature, leading, in this context, to an inherently hostile attitude without consciously reflecting upon it (Gebhard, 2000).

In classical moral psychology, the intuitive roots of moral judging and behavior were just rarely considered. The rationalistic research paradigm of the twentieth-century moral psychology is based on the works of Jean Piaget (1926). The direction of development posited by Piaget assumes a specific, egocentric thinking and leads to the abstract, logical thinking. Here, the skill of changing perspectives develops combined with a gradual detachment from external authorities. Lawrence Kohlberg (1969), who is probably the most prominent representative of this research tradition, describes the highest stage of development as being the autonomy of a principle-oriented thinking directly following the stage oriented at a principle of justice. But from a psychological point of view, human beings only have limited possibilities to reflect on the thinking process, which is responsible for the own ethical judgments and moral behavior. We become aware of the results, not of the mental information processes.

Studies about moral judgments showed that people rather doubted their reasoning than their judgment when facing irritations. Test persons were confronted with a breach of a taboo, and when they were not able to justify their judgment any further, they became insecure or made up preposterous reasons to maintain their justification (Haidt, Koller, & Dias, 1993). An understanding of moral judgments based on the current discussion about the significance of the sociocultural influence and intuitive decisions helps to understand the reasons for discrepancies between judging and acting or why apparently nonrational or rather nonscientific aspects play an important role in decision-making processes.

3 The Social-Intuitionist Model of Moral Judgment

The social-intuitionist model of moral judgment (Haidt, 2001) agrees with the social psychological view on the relation between perception and judgment. Furthermore judging complex moral issues is understood as a simultaneous process of situational perception and information processing (see Gilovich, Griffin, & Kahneman, 2002). The moral judgment or its justification afterwards is comparable to the behavior of a defense lawyer in court instead of the ideal of the unaffected and truth-searching researcher. And human beings do not judge as isolated individuals: "The social part of the social intuitionist model proposes that moral judgment should be studied as an interpersonal process" (Haidt, 2001, p. 814).

Embedded in the social context in which the subject and the object of judgment are situated, the reasons for the judgment often have an indirect origin and effect:

> "Moral reasoning is usually an ex post facto process used to influence their intuitions (and hence judgments) of other people. [...] Then, when faced with a social demand for a verbal justification, one becomes a lawyer trying to build a case rather than a judge searching for the truth" (Haidt, 2001, p. 814).

Humans possess a comprehensive pool of culturally passed-on convictions. Haidt refers to "a priori causal theories" (Haidt, 2001, p. 822) on which humans automatically draw when asked to justify their intuitions. The social dimension of Haidt's model posits that judging a situation or topic must also be understood as a socially influenced process. Humans live in social contexts, oriented at socially shared and internalized values and norms. Haidt characterized this phenomenon as the *chameleon effect*: people unconsciously imitate the convictions and values of their fellow human beings to whom they feel related. According to Haidt, the commonsense perception of morals suffers from a big illusion, referred as the *wag-the-dog illusion*: the relations between reflecting and judgment are thought in the wrong (namely, upside down) order.

Haidt (2001) describes six basic processes, which influence moral judgments:

1. **The intuitive judgment**: the evaluation of situations, persons, or topics is an integral part of our perception. The associative coping processes leading to judgment staying hidden. The categorization of our environment is based on internalized and, at most, successful heuristics (see Gilovich et al., 2002; Zajonc, 1980).
2. **The post hoc justification**: people start to give reasons for their intuitive judgments when they are asked to do so or when they are motivated otherwise (see Kuhn, 1991; Nisbett & Wilson, 1977). This kind of legitimation of the own judgment corresponds to the construction of hypotheses about the reasons for the own behavior. The justification for behavior or judgment does not happen before but rather after the intuitive judgment of an issue.
3. **The argumentative influence on the intuitions of a conversational partner**: when people start to explain themselves, their reasoning evokes associations and intuitive judgments by their conversational partner, which also get justified post hoc.
4. **The social influence**: often our intuitions correspond to the convictions predominant in a group that we feel related to or which is sympathetic to us. This phenomenon is discussed in more detail under the title “social persuasion” (see Chen & Chaiken, 1999; Petty & Cacioppo, 1986).
5. **The reflective judgment**: if a person has enough cognitive capacities and stays in a sufficient spatial and temporal context, a judgment can be the result of reflective thinking regardless of their possible consistency with our intuitions (Haidt et al., 1993). Counterintuitive judgment requires a great deal of critical distance toward the own behavior. Such a quasi-philosophical reflectiveness is, even if cognitively more complicated and not determining daily life, a valuable good in Western civilization. To train this philosophical way of thinking is a constitutive part of science and education and forms the starting point of current designs of models that foster the development of the decision-making competence in science education (see Eggert & Bögeholz, 2010; Reitschert & Hößle, 2006).
6. **The inner dialogue when changing perspective**: moreover, reflecting on the situation and the point of view of other persons can lead to new associations and intuitive judgments, contrasting preceding intuitions. Such an inner dialogue is supported in pedagogical contexts as the ability to change one’s own perspective and take on a different role (Hoffman, 1976). People put themselves in somebody else’s situation, try to understand their perspective, and, in that, generate new intuitions.

The social-intuitionist model of moral judgment is not anti-rationalistic because intuitive judgment is not uncorrectable or even of a higher moral quality. However, considering the fact that humans process information mainly unconsciously, intuitive judgments are unavoidable, and at the same time, they express our mental constitution. Below the surface of ethical arguments—no matter how complex they are—our intuitive beliefs operate as well. In this sense, intuitive judgments are not nonrational. They have their own logic, based on the cultural context and the biography and experiences of the individuals. In the following, ethically relevant intuitions are presented in the research program "everyday myths" as culturally rooted and socially imparted beliefs about mankind, nature, and technology, which influence discussions about socio-scientific issues on a hidden way.

4 Intuitive Beliefs About Mankind, Nature, and Technology

Since the 1970s students' alternative frameworks have been researched from a straight point of learning (see Pfundt & Duit, 1994). Numerous didactic studies have been aimed at ascertaining so-called misconceptions to find ways of replacing these by scientific concepts (see Gilbert & Watts, 2008). Consequently, a defamation of everyday life perceptions as misconceptions became common. Talking about misconceptions can lead to the epistemologically insupportable belief that teachers own the only and objectively true knowledge, just because they are experts and represent the scientific worldview. This hierarchization of different worldviews is problematic and counterproductive for a didactic attitude aiming at fostering educational processes that aim to make students aware of the philosophic reservations about stability, validity, and scope of scientific statements (see McComas, 1998). From this point of view, it is also important to deal with alternative beliefs and the worldview of students in an open-minded way.

The central assumption of the didactical concept and research program "fantasies of the every day" is that explicitly reflecting on our associations and intuitive beliefs deepens our engagement with the object of study and deepens the personal involvement with the educational content. This process can make scientific topics and abstract knowledge subjectively significant, and it can foster learning processes. Referring to the meaning of objects, Boesch (1980) distinguishes two processes of how individuals get a relationship to the world. He calls the two different modes "objectifying" and "subjectifying." Objectifying means learning about the general and at most science-based meaning of objects, while "subjectifying" refers to the symbolic meaning of objects. A house is objectively a place, which protects people against weather. Subjectively a house could have different meanings like being someone's home, a trustful place, a symbol of economical success, etc. According to this symbolic meaning, genetic engineering, for example, can activate a comprehensive array of ideas, hopes, and fears

(Gebhard, 2007). In this respect, ethically relevant beliefs about science and technology, which can be activated while engaging in scientific topics, are addressed by the already mentioned "everyday myths." Hence an essential intention of the "everyday myths" approach is a sensitization to intuitive judgments of students that are often disregarded in class due to their supposedly irrational or rambling character.

According to the social-intuitionist model of moral judgment, these beliefs about the world and idea of man influence ethical discussions and therefore moral judgments and behavior. The rationality of scientific approaches toward the phenomena of the world is often positively set apart from the ideas in everyday life, which are perceived as naive, emotional, or even irrational. This juxtaposition bares the risk of excluding these ideas from science classes. Important for the approach "everyday myths," however, is the basic assumption that both the scientific and the everyday approach to reality are understood as complementary rationalities. According to Boesch (1980), objectifying and subjectifying are bilingual approaches to understand phenomena of the world.

In the works of the Hamburg research group and on the basis of group discussions with students about genetic engineering, twelve ethical relevant beliefs were reconstructed (Gebhard & Mielke, 2003). In order to examine students' intuitive operating beliefs about genetic engineering, Gebhard and Mielke chose the qualitative method of group discussions, which seizes suggestions from philosophy for children (see Gebhard, Nevers, & Billmann-Mahecha, 2003; Nevers, 2009). The centerpiece of this method is to provoke a discussion between the participants by reading an open-ended story. The story contains a controversial conversation between two adolescents who represent divergent, justifiable positions. The story ends with a dilemma and the participants of the group discussion are asked for their opinion.

The discussions are analyzed according to the grounded theory approach. Typical "everyday myths" respectively intuitive beliefs about genetic engineering are, for example:

- "**Life is sacred**" (life has a dignity of its own).
- "**Nature is a meaningful idea**" (nature gives us moral orientation and it's forbidden to manipulate the natural order).
- "**Ambivalence of discovery and knowledge**" (knowledge and insight are Janus faced: on the one hand, humankind can free itself; on the other hand, knowledge is dangerous and unequal).
- "**Death and immortality**" (life-extending techniques are beneficial, and at the same moment, immortality is eerily aspiration).
- "**Health**" (healthiness has a dignity of its own and legitimate risky technologies).
- "**Belonging versus exclusion**" (if people are against new technologies, they can be excluded from society).
- "**Human as homo faber**" (humans have the skills and the urge to engineering and to forming the world).

- "**Human as creator**" (humans can create new life, they playing God).
- "**Human as machine**" (similar to machines, we can replace organs)"
- "**Perfection and beauty**" (we go for optimizing ourselves, and at the same time, being perfect is boring).
- "**Individualism**" (genetic engineering is the end of the individualism, and individualism has an intrinsic value).
- "**Language of genes**" (scientists can read the genome like a book).

In the following, the belief "nature is a meaningful idea" will be presented as an example. The general belief that nature has a strong intrinsic value could also be relevant for the students' image of chemistry as a laboratory science. The belief "nature is a meaningful idea" relatively often comes across in the involvement with genetic engineering, especially as a normative concept of nature, which guides us. This belief leads to the position: *Whatever is natural is good!* In the group discussions, we can observe the tendency to argue in the logic of a "naturalistic fallacy" (Frankena, 1939), because nature becomes the epitome of a normative instance, which sets the orientation for moral judgments and behavior. "Natural" and "morally correct" coincide in such naturalistic ethics. For example, in a sequence, when the participants discussed the possibility to select diseased genes:

> Just now I have this picture of animals in my head, I don't know, like when a tiger mom is having a tiger baby. Well, she has four and one of them is blind or something. Then she would reject it. And I don't know, I mean, that's nature and it (genetic selection) is left to humans themselves and I guess that it's not necessarily negative.

Against this background, changing the everlasting and constant nature shouldn't be:

> I don't know, I think we have screwed up nature enough, some things should stay natural.

According to the belief "nature is a meaningful idea," evolutionary positions often come across. This becomes particularly clear when employing scientific, evolutionary concepts, especially in evaluating genetic therapy. An evolutionary idea of man is referred to in the following quotations:

> For the ones affected certainly good, but even humankind is just a biological cycle, that you shouldn't retard for decades!
>
> For the individual an ideal solution. For humanity as a whole, however, not only good. So far the law of the strongest is applied (—he survived)... but illnesses were invented by nature to accomplish a selection which is disrupted, prevented.
>
> I think that it's a positive thing when brings about a relief for sick people. But what about natural selection?

"Natural selection" and "selection" are used remarkably often as categories for evaluating genetic therapy. Such eugenic and partly social Darwinian ideas become obvious in the apprehension that the "strongest" cannot prevail. Either when sick people are cured by gene therapeutic means or when too many people survive due to optimized agriculture by genetic engineering. In this kind of argumentation, a possible overcoming of hunger problems by means of genetic engineering is appreciated, indeed; however, the question arises whether this could be in the interest of natural selection. As a consequence of genetically supported overcoming of hunger problems, the strongest—in this case the ones with the most food available—could possibly not be able anymore to assert themselves. The argument of overpopulation is markedly frequent, as is demonstrated in the following quotation:

> Famine in Africa should be ended by nature.

5 The Efficacy of Reflections on Everyday Myths in Science Classes: Empirical Evidence

The central claim of the “everyday myths” approach is that by including intuitive beliefs in subject-related learning processes, a personal meaning can be constituted. Two interventional studies (Born, 2007; Monetha, 2009) showed that subject-specific teaching which explicitly addresses the fantasies of students and repeatedly refers to them as class is interpreted more meaningfully, is more motivating, and leads to lasting learning success.

Explicit reflections and discussions about intuitive beliefs in science classes could have an effect on motivation and learning efficiency. Monetha (2009) investigated this effect in an intervention study. It was a quasi-experimental research design that three grade 10th classes took part in. The acquisition of data occurred during 14 lessons per class. The investigation was conducted using a control-group design. The groups were comparable with respect to previous knowledge of genetic engineering, nonverbal cognitive abilities, performance in biology class, age, sex, motivational orientation, dispositional interest in genetic engineering and biology, academic self-concept in biology, self-efficacy, and epistemic conviction.

Against the background of the self-determination theory (Ryan & Deci, 2000), motivational factors were surveyed in the investigation. The results show, regarding psychological basic needs (see Bandura, 1977), that, above all, the experience of social relatedness is positively influenced by the consideration of “everyday myths,” maybe because the students get into personal and interactive reflections about their own visions of science. In addition the reflection on “everyday myths” influenced students’ comprehension processes: the control class did slightly worse in the achievement test than both intervention classes. This becomes clearer after 12 weeks: the students of the intervention classes can remember more content than the students in the control class. Against the background of our understanding that learning is always linked with the activation of the symbolic meaning of scientific topics and phenomena (especially if there exist an ethical connotation), we assume that appreciating personal concepts leads to a subject-related and apparently sustainable processing of the teaching material. The results of the follow-up study are especially pointing this direction.

In another experimental study with 203 participants, Gebhard, Mielke, and Oschatz try to activate the intuitive beliefs of the participants about genetic engineering and examined, among others, the effects of focused-thinking processes regarding biological topics (Oschatz, 2011; Oschatz, Gebhard, & Mielke, 2010). The students read a text about gene transfer. With the aid of a multiple-choice test as well as specifically developed transfer tasks for understanding the basic processes of gene transfer (Oschatz, 2011), the effects of processes of understanding were observed.

The results show that the control group solved the transfer task, which dealt with typical "everyday myths," significantly better than the experimental group. Regarding the multiple-choice tasks, there was a similar tendency. Apart from that we observed a "need for cognition" (Cacioppo & Petty, 1982) with the subjects. This is a personality characteristic, in which the students expressed joy about thinking and contemplation. People with a strong need for cognition enjoy thinking and invest a high analytical effort when they are offered an opportunity. People with a weak need for cognition avoid elaborate thinking if not "forced" to do so by corresponding challenges. The effects of the need for cognition were leveled by the activation of "everyday myths." While the subjects of the control group did better in depending on their need for cognition, the control group showed no differences. Obviously, the "everyday myths" keep the students very busy and distract from the teaching material at first (Oschatz, 2011).

The primary effect of the preoccupation with "everyday myths" can therefore be described as irritation at first glance, leading away from the practiced and efficient way of dealing with a topic. At second glance this is not surprising, though: if we want students to deal with teaching material that is emotionally touched and confronted and personally involved, it will take more than a smooth learning process. This can of course be irritating and "go astray". However, what the interventional studies show is that irritating depth is beneficent: when fantasies are appreciated and repeatedly made subject to explicit and shared reflection, even though they digress, teaching that considers "everyday myths" is experienced more meaningfully by the students and supports their motivation.

Taking into account the "everyday myths" and the related irritations can, in this sense, become the decisive moment of the educational process. Apart from that, the culturally rooted beliefs about the world, nature, and human beings are especially important for educational processes—particularly in the context of the discussion about socio-scientific issues—because they connect class to cultural and social concepts as well as to implicit worldviews and ideas of mankind. In addition, they do not stay within the limits of a specific subject, and their explicit reflecting secures the interdisciplinary approach. We proceed on the theoretical assumption that the integration of complex perceptions and the processing of different approaches need to be counterbalanced by additional cognitive effort and that this additional cognitive performance could support learning.

6 Parallels to Socio-Scientific Issues in Chemistry Education

Questions of chances and risks of scientific research require basic skills in ethical reflecting and opinion forming. Therefore, the array of ethical themes in chemistry classes ranges from nutrition in elementary to climate change or discussions about nanotechnology in higher grades. These are themes that range from those that affect students in their daily lives up to topics which get large attention in the media.

The named studies about the role of intuitive beliefs in considerations with ethically relevant or ethically connoted contents focused on genetic engineering. Although contemporary moral psychology ascribes a high importance to intuitive judgments, there are no investigations about the role of intuitive beliefs in the field of socio-scientific issues. A few above-described intuitive operating “everyday myths” could also be relevant for chemistry education.

The above-outlined belief “nature is a meaningful idea” refers to the fundamental differentiation between “nature” and “culture” and between “natural” and “artificial” or “industrial.” Chemistry education deals with something artificial and is associated more with “risky” industries than with “healthy” nature is a common belief in daily life, which can influence the attitudes against chemistry and chemistry education as a whole.

The fantasy “ambivalence of discovery and knowledge” entails the view that scientific discovery and technological development are the inevitable way of human development and are both a blessing and a curse. According to the public discussion about the capabilities and risks of the nanotechnology (see Barben, Fisher, Selin, & Guston, 2008), it could be sensible to hold the discussion on the fundamentals of our attitudes against science and chemistry in particular. Nanotechnology could activate feelings of fascination and fear at the same time, similar to the polarizing debate about genetic engineering.

Another topic, which can influence judgments about socio-scientific issues in the context of science education, is the relationship between the concepts “chemicals” and “health.” People tend to be negatively biased toward chemicals because they can be poisonous for organisms and the environment. On the other hand, people do not typically pay attention to everyday chemistry, such as when people bake a pie with baking soda or take a headache pill. The connotation that chemicals are not natural and maybe toxic is in opposition to the fact that we can describe the whole existing world in chemical terms.

7 Implications for the Open-Minded Science Teacher

Highlighting the intuitive dimension of moral judgments also leads to consequences for the stance of science teachers. Apart from reinforcing argumentation skills, a broader openness and sensibility to the broad array of morally relevant intuitions and their implicit effects should be fostered. Reflections about culturally rooted and intuitive operating beliefs are an advantage for meaningful and effective learning processes. Also, from a social-intuitionist perspective, science teachers cannot escape the cultural dimension of their discipline. In the international science education community, Aikenhead (1997) discusses in the 1990s the significance of the cultural background in his works on "cross-cultural education." Currently the consideration of the cultural dimension in science class is under discussion with the title *Cultural Studies of Science Education* (see Tobin, 2009).

There is a strong interdependency between science and culture, and this interdependency is not only a theme for history or philosophy classes. Due to the comprehensive cultural influence of science and technology in modern societies, the philosopher Mittelstraß demands the responsibility and the localization of ethical considerations in the scientific disciplines itself. According to Mittelstraß (1996), explicit addressing of ethical questions in the context of scientific disciplines reinforces the formation of *knowledge of orientation* instead of the dominance of *knowledge of instruction*: "The awareness of this responsibility requires indeed a special *scientific ethic* if not a special ethics. More precisely this requirement is based on training special skills, for example reflecting competences, theoretical competences, problem solving- and judgment competences" (Mittelstraß, 1996, p. 45, translated by the authors).

We shouldn't reduce the scope of socio-scientific issues on risky technology. In comparison to the established technology impact assessment, the impact of scientific theories on the self-concepts and the worldviews of humans play a minor role. Regarding the "everyday myths" approach, it also seems necessary to foster a discourse about the impact of scientific concepts and theories in the field of socio-scientific issues. The philosopher Thomas Metzinger describes such a responsible involvement with the scientific explanatory claim as opposed to human and nature as "anthropology assessment" (Metzinger, 2000a, p. 62, translated by the authors, see also Metzinger, 2000b). The idea of anthropology assessment is the counterpart to technology assessment concerning the material consequences of science. Analogously, we name the reflection of mental consequences and effects of science on our worldview and idea of man *theory assessment*. Relevant to this kind of assessment are scientific theories, which can influence our worldview and ideas of man. Examples are the significance of neurobiological research regarding the discourse about free will and determination or the conflict between the theory of evolution and theology of creation. For that matter, chemistry education is highly relevant for our self-perception and worldview even though the scientific and seemingly unbiased concepts have a more subtle effect and often influence thinking only in the background as intuitive perceptions. The "everyday myths" discussed above, which carry these worldviews and ideas of man, provide the class material for this "theory assessment" and for lively and reflective debates about the subjective and cultural meaning of biology, physics, or chemistry.

The intuitive dimension of decision-making competence and the cultural dimension of science classes are an educational challenge and require special sensibility and care of students as well as teachers. The support of ethical reflective and argumentative competence represents the cognitive dimension of decision-making competence. It is about applying knowledge and performing logical operations (Betsch & Haberstroh, 2005; Gresch, Hasselhorn, & Bögeholz, 2013). As important as these skills undoubtedly are, without corresponding social, empathic, and communicative skills (e.g., coping with border crossing and allegedly irrational behavior), decision-making competence remains soulless and tentative. It is also about taking somebody else's perspective, enduring controversies, and developing a sense for ethical sensible topics (see Hoffman, 1991).

Thus, science teacher education in the field of socio-scientific issues also means that during their studies, future teachers acquire the ethical and philosophical knowledge as well as social and communicative competences that are important for a discussion of ethical topics and the related intuitive judgments. In this way, a didactic attitude is supposed to be developed, which is able to cope with the diversity of ethically relevant perceptions or intuitions. The point here is not simply the support of logical thinking and the ability to change perspectives but rather to moderate divergent opinions, incorporate intuitive judgments, and be sensible toward the individuals' visions of science.

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Part II
Research and Practice

Implementing Inquiry-Based Science Education to Foster Emotional Engagement of Special-Needs Students

Simone Abels

Abstract Affective dimensions are key determinants for the successful performance of all students at compulsory level, but for students with special educational needs, they become even more important. The focus of this chapter is students with cognitive and emotional/behavior disorders. Learning environments have to be carefully designed so that these students can develop a feeling of success, ability, and social embeddedness in order to cope with their affective lability. Following the idea of "science for all," every student is entitled to develop skills in science to the fullest potential on the basis of appropriate educational opportunities. This chapter illustrates a case study using the approach of emancipatory action research to investigate how the implementation of the often recommended approach "inquiry-based science education" can foster the emotional engagement of special-needs students (5th and 6th graders). Two out of ten students of a special-needs class were chosen for deeper analysis. Their special educational needs were diagnosed in two focal areas of support: "emotional and social development" and "learning". The aim of the action research study was to increase active participation and engagement in working on a chemistry-related topic by changing established teaching approaches. Diagnostic assessment and video analysis were used to observe the alteration of two students' behavior in chemistry lessons in relation to the implemented adaptation of instruction. The analysis showed that in a guided inquiry-based setting, it was possible to reveal students' methodical, social, and personal abilities enabling them to engage in a chemistry-related task.

Keywords Special education • Inquiry-based learning • Engagement • Action research • Video analysis

1 Introduction

It is an educational and political demand to adapt teaching practices to the specific needs of all students in one school, including students with special needs. Although many stakeholders agree with the claim "science for all" of the NRC (National

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Research Council, 1996), there is a lack of research on special educational needs in the context of science education (Browder et al., 2010). While the existing research mostly focuses on language and mathematics learning, science learning, especially chemistry, with special-needs students is rather neglected (Scruggs, Mastropieri, & Okolo, 2008). The study at hand contributes to close this gap by investigating the implementation of recommended teaching strategies in chemistry education with special-needs students, more precisely students with cognitive and emotional/behavior disorders. For such cases, a growing number of science education studies are recommending a carefully scaffolded inquiry-based learning approach (e.g., Villanueva et al., 2012) which will be dealt with in this chapter.

2 Rationale of the Study

In 1994 the UNESCO *Salamanca Statement and Framework for Action in Special Needs Education* recorded that students with special educational needs must have access to education facilities "which should accommodate them within a child-centered pedagogy capable of meeting [their] needs" (United Nations & Ministry of Education and Science Spain, 1994, p. viii). Every student has the right to education "on the basis of equal opportunity" (United Nations, 2006, p. 16). Equal opportunity means "genuine access to learning experiences that respect individual differences and quality education for all focused upon personal strengths rather than weaknesses" (Meijer, 2010, para. 2). Nevertheless, in some countries children do not have equal opportunities yet (Sliwka, 2010). Some countries still have segregated school systems and struggle with the inclusion of special-needs students. The achievement of special-needs students is often considered as insufficient to include them in mainstream schools (Steele, 2004). Science instruction demanding high-level thinking and problem-solving strategies is especially often estimated as too difficult and over challenging for (mildly) disabled students (Steele, 2004; Sullivan Palincsar, Magnusson, Collins, & Cutter, 2001). However, more and more studies reveal that special-needs students can improve their performance immensely if appropriate teaching strategies like inquiry-based approaches are used and based upon the specific learning needs of the students (Browder et al., 2010; Villanueva et al., 2012). But this change of teaching practice has shown to be very difficult for teachers to implement (Courtade, Browder, Spooner, & DiBiase, 2010; Villanueva et al., 2012).

The goal of this study is to show one way inquiry-based strategies can be implemented in a special-needs class and to identify the effects of the implementation on special-needs students. The present study is focusing on mildly handicapped students, diagnosed in the focal areas of supporting "emotional and social development" as well as "learning", which were part of an inter-year class (5th and 6th grades) at an urban special-needs school. Students who need support in emotional and social development often suffer from bad family experiences, such as parental neglect, verbal and physical abuse, or other severe difficulties in their social environment. As a result, they receive little educational stimulation. Usually, they have no strategies to cope with their intense experiences but aggression, anger, and violence. More carefully stated, the interaction between their milieu and personal development is very complex and diverse (Kultusministerkonferenz, 2000).[1] Thus, the present study focuses especially on the effects of the inquiry implementation regarding students' affect.

Students with emotional disorders need—more than other students—feelings of success, ability, and social embeddedness to cope with their affective lability. Teachers have to be aware of students' emotions to design the learning process accordingly (Boekaerts, 2010). "Emotions can overwhelm thinking and concentration so that intellectual efforts are swamped and rendered wholly ineffective" (Alsop & Watts, 2003, p. 1043). Learning opportunities are mandatory which observe students' emotional stage next to their developmental age, their social situation, as well as their individual prior skills and knowledge. Their horizon of experiences can be very specific and this has to be taken into account in every school subject to make learning meaningful for the students (Manske, 2009).

Here, science is seen as particularly relevant as the students can learn about nature and technology that is not only linked to their surroundings but also enables them to extend their horizon of experiences. "Students with disabilities, many of whom have had more limited life experiences, can benefit from the systematic study of the world of living and non-living things" (Mastropieri et al., 2006, p. 131). "Moreover, it ensures that *all* students learn about science and become scientifically literate, which is a stated goal in the National Science Education Standards (NRC, 1996)" (Trundle, 2008, p. 80 original emphasis). However, the study of Maria, dos Santos, and Fleury Mortimer (2003) shows that working with phenomena close to students' surroundings is not enough to learn a science subject. "The competence of the teacher in installing and maintaining a student-centred approach in the classroom and her skilfulness [sic] in relating chemical knowledge to everyday phenomena were not enough to guarantee an affective proximity between students and school chemistry" (2003, p. 1109). The emotional reactions of the teacher and a constant reflection of these reactions were crucial.

Other studies show that traditional approaches in science like the use of textbooks, remembering verbal instructions, or other language-based strategies are not effective and can be demotivating for special-needs students (Scruggs et al., 2008; Trundle, 2008). Teaching strategies have to be applied that take their affective and cognitive challenges into account.

[1] It has to be acknowledged that attributes of the students cannot be taken as explanations for difficulties in school. "More and more people are convinced that the medical approach of the concept of 'handicap' should be replaced with a more educational approach: the central focus has now turned to the consequences of disability for education. However, at the same time it is clear that this approach is very complex, and countries are currently struggling with the practical implementation of this philosophy" (Meijer, 2010, para. 3). This is also called "the social model where a child is perceived as having an impairment, but is disabled by attitudes and the environment" (Kearney, 2011, p. 6).

Promising strategies that can enhance science achievement for special-needs students are vocabulary enhancements and text adaptations (Markic & Abels, 2013), problem-solving, and hands-on activities (Bay, Staver, Bryan, & Hale, 1992). Scruggs and Mastropieri's study (1995, p. 268) suggests that mildly disabled students "are very capable of participating in, and benefiting from, inquiry-oriented science" when it is carefully scaffolded with, e.g., graphic organizers, guiding questions, multiple ways of presentation, etc., that take the specific learning needs of the students into account (cp. Courtade et al., 2010). These recommendations are consistent with the demands on the design of general classroom practice named by the expert groups of the European Commission (Gago et al., 2004) and the Organisation for Economic Co-operation and Development (OECD; Dumont, Istance, & Benavides, 2010). Learning environments should be inquiry based, context based, student centered, self-directed, adapted to the learner, collaborative, and interdisciplinary. As these principles are considered to be significant for general education students' successful learning, keeping these conditions is suspected to be even more important for special-needs students.

Also the so-called Rocard report of the European Commission (2007) recommends inquiry-based science education to deal with the diversity in a classroom. What the recommendations do not tell is how to implement inquiry-based learning for special-needs students who are not used to that way of learning in science. And there is especially a lack of research on the topic in chemistry education. Chemistry is one of the neglected subjects in special-needs education. The additional challenge is that the students who are emotionally and socially unbalanced easily feel overwhelmed, frustrated, and angry when they are confronted with unknown strategies and new structures.

Accordingly, the research question addressed here is: How can inquiry-based science education successfully be implemented in chemistry-oriented lessons attended by students with cognitive and emotional/behavior disorders? Success is indicated by the absence of negative emotions and destructive behavior as well as by the achievement in topic-related skills. The main purpose of the study was to explore and better understand how the emotionally sorely afflicted special-needs students engaged in the newly implemented inquiry-based learning approach.

3 Inquiry-Based Learning to Engage Special-Needs Students

Science education experts have been promoting the inquiry-based approach as it increases interest in as well as motivation to learn science and facilitates the engagement of students across the ability range (European Commission, 2007; Koballa & Glynn, 2007). Additionally, more students seem to prefer inquiry-based learning to traditional instruction (Scruggs, Mastropieri, & Boon, 1998). However, there is still a lively debate about how to design learning environments best to further inquiry-related abilities and whether or not all students are capable of conducting scientific inquiries as this not only furthers but also requires a number of skills (Hmelo-Silver, Duncan, & Chinn, 2007; Kirschner, Sweller, & Clarke, 2006; Lee, Buxton, Lewis, & LeRoy, 2006).

The National Research Council (2000, p. 19) describes fundamental abilities needed for scientific inquiry. Displayed below are the skills necessary as of grades K–4 (which apply for the 5th and 6th graders of the study at hand due to their developmental age and cognitive learning abilities):

- “Ask a question about objects, organisms, and events in the environment.
- Plan and conduct a simple investigation.
- Employ simple equipment and tools to gather data and extend the senses.
- Use data to construct a reasonable explanation.
- Communicate investigations and explanations.”

As not all students can be expected to have the knowledge and skills needed to do and discuss inquiry right from the beginning, successive implementation is necessary. “Instruction should gradually and systematically move from Level ‘0’ activities with the ultimate goal being some Level ‘3’ activities” (Lederman, Southerland, & Akerson, 2008, p. 32). Blanchard et al. (2010) illustrate the different levels and increasing student responsibility in the table below (Table 1).

The levels should be applied appropriately in terms of the situation, students’ abilities, topic, etc. Consequently, level 3 is not automatically the aim for every student. Overall, students—and not only those with special educational needs—benefit from guided inquiry rather than open inquiry, with adapted structuring, differentiated support, and cooperation (Scruggs et al., 2008). “There is growing evidence from large-scale experimental and quasi-experimental studies demonstrating that inquiry-based instruction results in significant learning gains in comparison to traditional instruction and that disadvantaged students benefit most from inquiry-based instructional approaches” (Hmelo-Silver et al., 2007, p. 104). More and more studies revealed that it is possible to conduct inquiry-based science education with special-needs students when it is carefully and clearly scaffolded (Villanueva et al., 2012). The studies vote for guided inquiry as this level balances openness and structure, which is recommended for students with special needs to avoid mental overload and thus frustration, refusal, and anger (e.g., Bay et al., 1992; Scruggs & Mastropieri, 2007; Werning & Lütje-Klose, 2007).

Table 1 Levels of inquiry

	Source of the question	Data collection methods	Interpretation of results
Level 0: verification	Given by teacher	Given by teacher	Given by teacher
Level 1: structured	Given by teacher	Given by teacher	*Open to student*
Level 2: guided	Given by teacher	*Open to student*	*Open to student*
Level 3: open	*Open to student*	*Open to student*	*Open to student*

According to Lynch, Kuipers, Pyke, and Szesze (2005), inquiry-based approaches do not only contribute to avoid these emotional reactions but even foster engagement of disadvantaged students including students with disabilities. In their study "engagement is a multilevel construct (basic and advanced) that involves students' use of [cognitive, affective, and behavioral] strategies for sustaining learning activity" (Lynch et al., 2005, p. 924). For low achievers basic engagement is viewed as a positive step, i.e., they actively participate in classroom actions, follow instructions, and attend to the behavioral rules of an activity (ibid.). In line with the focus of the present study, this description is enriched by the definition of Fredricks, Blumenfeld, and Paris (2004, p. 60, original emph.): "*Emotional engagement* encompasses positive and negative reactions to teachers, classmates, academics, and school and is presumed to [. . .] influence willingness to do the work." Jang, Reeve, and Deci (2010, p. 588) summarize engagement as "the behavioral intensity and emotional quality of a student's active involvement during a learning activity." The definition of basic engagement by Lynch et al. (2005) and emotional engagement by Fredricks et al. (2004) is used in the present study to observe changes in the affective behavior of the students.

Students with cognitive and emotional/behavior disorders hardly show engagement as defined above due to the social and emotional challenges they undergo every day. The level of engagement is dependent on the emotional form of the day of each student, which can be influenced by cognitive and social stimuli and can change abruptly (Bergsson, 2006). Accordingly, it is eminently important for the emotional engagement of the students to provide learning opportunities that give them a feeling of autonomy, competence, and relatedness (Deci & Ryan, 2000). The authors state that the degree to which these three needs are satisfied determines the level of active engagement in and maintenance with an activity (ibid.). For example, autonomy-supportive teachers engage students in a learning activity "by taking the students' perspective; identifying and nurturing the students' needs, interests, and preferences; providing optimal challenges; highlighting meaningful learning goals; and presenting interesting, relevant, and enriched activities" (Jang et al., 2010, p. 589). Positive feedback by the teacher can satisfy the need of competence giving the students the feeling that they are responsible for their learning progressions. Reliable relations provide a secure basis—"a needed backdrop"—for students to sustain learning activities (Deci & Ryan, 2000, p. 235). Especially students with emotional disorders rarely experience secure and steady relationships so that the satisfaction of the need "relatedness" in school is remarkably important.

4 Framework of the Study

In special-needs education, it is first and foremost important to diagnose the individual preconditions of students and their socioenvironment to differentiate teaching accordingly (Watkins, 2007). Although it is state of the art to orient on the strength of the students, I will also describe the preconditions of the students in a somehow deficit-oriented way so that the reader can understand the change of behavior before and after the study at hand.

I conducted the case study at a special-needs school for students with the focal points of supporting “learning” as well as “emotional and social development”. The atmosphere at this school, where I worked as a student teacher after receiving my PhD, was remarkably affected by the students’ extreme experiences, thereby leading to little educational stimulation. “This emotional strain was visible in aggression, anger, conflicts, violence, disrespect and swearwords among the pupils and more or less overtly towards teachers as well” (Abels, 2012, p. 169). At that school, I taught an inter-year class of ten students, six boys and four girls aged 10–12 (5th and 6th grades), in science. Three students had migration background. The socioeconomic background of all students was low and most of them suffered from a difficult family situation as well as unsteady school careers. Reading and writing skills differed immensely. Some students read and wrote just words, others could read and write short coherent texts. There was an erratic atmosphere of study in the class due to the emotional form of the day and social interactions happening. The students had no strategies to cope with conflicts they were personally involved in. Peer discussions and group work often led to arguments. Achievement levels, active participation, and speed of work were diverse. The students were primarily used to rather traditional classroom practice, with a focus on “lectures, class reading, completing worksheets” where “students are passive learners” (Hewson, Kahle, Scantlebury, & Davies, 2001, p. 1131). The reasons for this form of teaching were mostly of disciplinary nature. Additionally, the traditional settings were structured and non-overcharging, which enhanced concentration of the students.

I visualized and documented the individual preconditions of the students described above based on diagnostic assessment (Watkins, 2007) like conversations with the classroom teacher, available files and reports, as well as my own observations of the students during and outside class. Besides documenting demographic data, I observed their linguistic and communicative skills, their emotional and social behavior, their ways of learning and performance, as well as skills concerning subject matter and methodical and procedural knowledge.

Additionally, I detected that the students were often engaged in activities outside the subject area, had a high need for movement, were seeking affirmation from teachers as well as other students, and showed the highest engagement when collaborating and when they were given credit for something they had done. Most remarkably, the students of this class not only expressed their values, beliefs, and emotions clearly and strongly, but they also showed a tremendous sense of social justice. Furthermore, they often hesitated to embark on new challenges and used several avoidance strategies expressed in aggressive behavior, defense, distraction, ignorance, anger, etc.

On these grounds I decided to change classroom practice. I was looking for a teaching approach that would consider the cognitive and affective preconditions and basically engage the students in chemistry learning which means in this case to sustain a learning activity by the use of cognitive, affective, and behavioral strategies (cp. Lynch et al., 2005). As outlined above, inquiry-based learning is seen as appropriate to fulfill these demands in special-needs contexts. I selected level 2 (guided inquiry) to be the optimal aim for my students as it balances structure and autonomy (cp. Jang et al., 2010). Being the researcher and science teacher at the same time, I implemented the inquiry approach in my special educational needs class with an exploratory researcher's view on its success. I wanted my science teaching practice to be best suited for the students.

Two boys of the class were chosen for deeper analysis. Comparing the two different students should help to be more precise about the interpretation of the data. The students were selected because they differed clearly in interest, emotional and social development stages, as well as previous knowledge and skills in science:

Lennard[2] 10 years old; developmental age is two or even 3 years less; very curious and imaginative; needed and demanded a lot of affection; was easily distracted; avoided working on new exercises; afraid of new challenges; often refused to participate; in science classes, showed broad knowledge for his age and asked questions interestedly

Paul[2] 12 years old; class representative; wanted to be considered cool and therefore often pretended to be dull; dominated by the conflict "independence vs. acknowledgement" (Bergsson, 2006); able to work quite speedily and with high engagement; as much as he liked to help others, he also liked to distract them; refusal strategy was to behave disrespectfully toward teachers; in science classes, behavior and engagement depended on his mood and state of mind on a given day (cp. Abels, 2012)

This section has demarcated the "individual unit" of the study, which classifies the analysis as a case study (Flyvbjerg, 2011). Case study is an appropriate method as it allows evaluating an educational experience very specifically (cp. Lloyd, 2010). It is usable if there are how and why questions about contemporary events and if there is no control of behavioral events (Yin, 2009).

The research question of the case study was the following: How can guided inquiry (planning, conducting, and interpreting a scientific experiment) successfully be implemented in a chemistry class attended by students with cognitive and emotional/behavior disorders? Success is indicated by basic engagement and active participation as well as by the achievement in topic-related skills. As outlined above the main purpose of the study was to explore and better understand how the emotionally sorely afflicted students of the class handled the implementation of guided inquiry. The hypothesis was that guided inquiry was appropriate to engage the students in chemistry learning, so that they would not show their usual emotional lability but participate persistently in the task.

[2] Names were changed.

In the following, the design of the teaching unit and the associated aims for the students to reach over time are described. In addition, categories indicating the level of coping with the inquiry-based tasks were developed out of these aims.

5 The Teaching Unit

A 9-month period was used to observe the preconditions of the students and to implement inquiry-based learning successively with several tasks, such as electricity or thermodynamics. The whole period was needed to observe changes in the students' emotional engagement. The topic "states of matter" was then taught to lead the students more into chemistry learning. The topic of the teaching unit is—on a basic level—set by the science curriculum for students of that age (10–12 years) with the focal points of supporting learning[3] (Senatsverwaltung für Bildung [Senate Department for Education Youth and Sports] 2005). I realized how fascinated the students were playing with the ice outside (it was winter) and valued their positive behavior as a good starting point for the teaching unit using water as the example to study states of matter. Besides, water has a strong appeal for students around that age in general (Meier, 2000), and students can harmlessly and autonomously conduct experiments about it. Furthermore, states of matter was chosen as it is one of the rare topics for students of that age that has at least a peripheral connection to chemistry education which is often neglected in special education. Like a spiral curriculum suggests, the students should learn first concepts of the topic early which they can build on later when learning the particle model in that context, for example.

5.1 Targeted Skills During the Teaching Unit

The chosen topic for the implementation of inquiry-based learning was states of matter using the example of water. Targets were set for four competence areas: subject matter, personal skills, methodological skills, and social skills. The objectives concerning subject matter are given by the national curriculum for students in 5th/6th grade with the focal points of supporting learning (Senatsverwaltung für Bildung, Jugend und Sport Berlin 2005), for example:

- The students handle materials safely and with discernment.
- They explore characteristics of substances with the help of basic experiments.
- They explain different states of matter and name the technical terms.
- They classify changes of states of matter and label them correctly.

[3] This is the applicable curriculum. There is no specific curriculum for students with emotional/behavior disorders.

Table 2 Aims of the teaching unit and indicators of managing guided inquiry (cp. Abels, 2012)

Personal skills	Methodological skills	Social skills
Autonomy	Formulating assumptions Planning and conducting experiments Observing Systematically describing Documenting the results in protocols	Interacting Cooperating Helping each other Discussing instead of arguing Observing rules
"*Self-dependent planning, experimenting and recording indicated that the pupils were able to manage the phases of an investigation relevant in guided inquiry*." (Abels, 2012, p. 170) **Self-dependence**	"*The better the ideas the pupils had for problem-solving, the better their realization of inquiry*." (ibid.) **Ideas for problem-solving**	"*If more issue-related dialogues were held in comparison to non-issue-related ones, the pupils showed that they could manage the cooperative part of guided inquiry*." (ibid.) **Subject-related dialogues**

The following table shows the respective learning targets in three competence areas (Table 2). Certain observations in students' behavior were indicating when and if these targets could be attained (added in italic in Table 2). A derived category is emphasized in bold letters.

As the respective curriculum (Senatsverwaltung für Bildung Jugend und Sport Berlin, 2005) suggests, all four competence areas are directly related to engagement in relevant and meaningful learning. Subject matter skills develop during the involvement with interesting problem-based challenges. Personal skills develop in situations of appreciation and in the successful mastery of problem-solving. While methodological skills develop during the work on meaningful and relevant tasks, social skills manifest themselves as the increasing ability to manage exercises in teams.

The competence areas can be transferred to Deci and Ryan's (2000) psychological needs of autonomy (personal skills), competence (visible in subject matter and methodological learning), and relatedness (social skills). Diagnostic assessment of the skills was done by observations and discussions with the classroom teacher during the whole 9-month period. Video analysis was added for a short period (90 min) of guided inquiry.

To facilitate the acquisition of these competences and to reach the aims, the teaching unit was designed as follows.

5.2 *Successive Implementation of Inquiry-Based Learning*

The teaching unit was split in three phases. First, it started with some "cookbook" experiments (inquiry level 0; see Table 1) to link the tasks to the methodical abilities of the students and to practice keeping the minutes. This phase was also necessary to reduce uncertainty among the students about following procedures, handling materials, formulating hypotheses, etc. Its success was indicated by the decreasing number of questions the students asked the teacher.

Second, a learning circle was conducted (lasting four double lessons) containing theoretical and experimental stations to establish existing prior knowledge in the field “states of matter.” For example, a basic task was to cook water in a pot holding a glass lid above it and observe the changes of the state of matter. The students had to document their observations precisely, draw a sketch, and add the right terms which they could learn in a theoretical station. The experimental tasks were gradually opened to level 1 and performed more and more collaboratively. At the beginning of this phase, the students needed much support and well-structured scaffolding to manage the teamwork. They struggled with role-taking and entering into discussions without conflicts. Therefore, students were supported with explicit descriptions of their role (e.g., minute taker, time keeper, material provider, team leader, etc.), a small-step manual for their exercises during the experimenting, and precisely formulated questions to be discussed. The students learned to form teams and to decide independently which task they wanted to do first, taking into account a marked degree of difficulty. Furthermore, they got used to self-control options and to drawing help cards (described below). Giving the students the feeling and the confidence that they can manage scientific tasks successfully and self-directed reduced spontaneous defensive attitudes and utterances like “I can’t do that!” or “That will never work!” Fear of failure became successively less perceptible in the classroom.

Third, the class was opened to guided inquiry (lasting three double lessons). Four questions were suggested to be answered with a self-elaborated experiment. The questions were assigned and differentiated by degree of difficulty according to the students’ prior knowledge. As he had a pond behind his home, Lennard chose to work on the problem “How can fish survive in a lake frozen solid?” (labeled as average difficulty). Paul decided to work on this problem with Lennard.

I provided a multistage support system to ensure that the students would have the opportunity to experience autonomy, competence, and relatedness (cp. Deci & Ryan, 2000). They should feel success instead of frustration and mental overload. To experience a sense of achievement in meaningful learning situations helps special-needs students to cope with their fear of failure and to reduce emotionally charged avoidance strategies (Werning & Lütje-Klose, 2007), which I sought for the selected students. Every step of the students’ investigation could either be done self-directed or, if they had no idea how to proceed, they could find help cards and materials providing hints. If necessary the multistage support system that was provided should gradually guide them through the steps of a scientific investigation (National Research Council, 2000). Physical boxes were provided with different materials or help cards inside (Fig. 1). The students were supposed to access the boxes sequentially, i.e., they moved from box 1 to 2 to 3, etc. until they feel that they have received a sufficient amount of support. The more boxes the students would use, the higher the level of support for them. Box 1 just visualized the task to

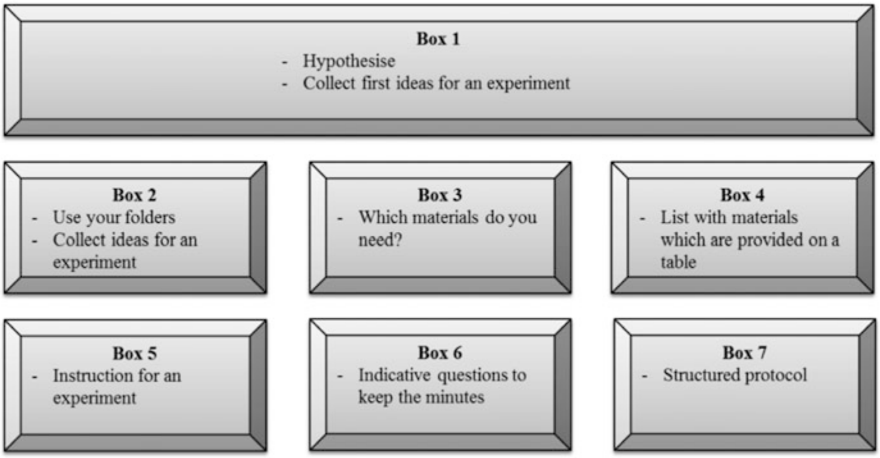

Fig. 1 Multistage support system

be done for everybody. With boxes 2–4, the task would have still been considered level 2 (guided inquiry), while with boxes 5–7, it would have shifted to level 1 (structured inquiry).

The next section explains how the accomplishment of the teaching unit was investigated and how the teaching practice was observed and analyzed.

6 Action Research in Special-Needs Education

To investigate how the level of engagement of the special-needs students was affected by the adaptation of classroom practice, an action research approach was used (Altrichter, Feldman, Posch, & Somekh, 2007). As I was the science teacher of a special-needs class and a chemistry education researcher in a dual role, I decided to follow the emancipatory action research mode (Grundy, 1982) described also in Mamlok-Naaman and Eilks (2011). In action research, data collection and methods of analysis do not differ from other forms of evaluation, but the aims and perspectives are different. Data is collected to validate particular decisions and approaches as well as understand certain situations. Moreover, the process is documented to track reflective practices and occurring changes. The knowledge gained is used to develop practice (Patton, 2011). Consequently, such studies serve to challenge common school practices and to work for social change "by engaging in a continuous process of problem posing, data gathering, analysis, and action" (Cochran-Smith & Lytle, 2009, p. 40).

Although there are only few action research studies in special-needs education, action research is seen as a successful approach to improve teaching and learning in these schools (O'Hanlon, 2009). Lloyd (2010) conducted a case study in special education based on critical action research[4] with 15 teachers. She says, "it is absolutely appropriate, indeed essential, for teachers to use such a model of critical action research as a tool for changing practice and as a means to enlightening and empowering themselves and their pupils and other involved agencies in order to develop genuinely participatory inclusive education for all" (Lloyd, 2010, p. 1129). Insights and discussions from special-needs education are often used as a starting point for the development of inclusive settings, which increasingly involves persons concerned with general education (Meijer, 2010; United Nations, 2006). Also the daily practice of chemistry teachers has to be empowered for change in terms of the inclusive demands posed by education policy. Action research is an essential means (cp. Lloyd, 2010) to drive forth this beginning development in chemistry education.

6.1 Data Collection and Analysis

I wanted to track how the change of classroom practice, i.e., the newly implemented approach of inquiry-based learning, affected the level of engagement of the students. In addition to direct classroom observation, I videotaped a double lesson of guided inquiry (third part of the teaching unit, see above). Only the part where the students actively planned and experimented was recorded, whereas the parts of discussion and reworking the students' concepts were not. According to my observations it was often difficult for the students to start a task. That is why especially the phases of planning and conducting an experiment should be revealing in terms of accomplishing the task. Those are the first steps to take self-regulated and without direct teacher control. The video data is the main focus of the following analysis as guided inquiry was the teaching strategy to be implemented in the long run.

The video analysis would give me an opportunity to reflect on action with some distance. Video recording is recommended when teachers analyze their own classes (Altrichter et al., 2007). Furthermore, the data produced by video analysis is not influenced by students' attainment levels like interviews, for example, would be. Due to the students' language skills, I decided not to use questionnaires.

Concerning ethical issues, permission to videotape the students was given, data was anonymized, and the video was only seen by the researcher/science teacher and the classroom teacher.

As theoretical and curriculum-based aims and indicators were used to analyze accomplishment of the implementation, I decided to use the deductive procedure "contentual structuration" of the method "content analysis" (Flick, 2009; Mayring, 2007). The videotaped lessons were coded by means of a category system which will be explicated in the following section. The tool "Videograph" developed by

[4] Critical action research is regarded "as the embodiment of the democratic principle, leading to empowerment, enlightenment and emancipation" (Lloyd, 2010, p. 112).

Rimmele was used to facilitate the analysis technically (cp. Seidel et al., 2006). Transcripts helped to explicate some core categories with standard examples. The coding was validated argumentatively with the classroom teacher, who knew the students for more than a year. The classroom teacher and I agreed on the majority of the codings. Where we did not agree at first, agreement was achieved by discussion about the video data in relation to our observations.

These aspects (documentation of the research process, using systematic coding procedures and rules, interpretation in a team) aimed at intersubjective inferability, seen as the highest quality factor in qualitative research (Steinke, 2012).

6.2 The Category System of the Analysis

To recall, the main purpose of the study was to explore and better understand how the emotional engagement of the emotionally sorely afflicted students of the class was influenced by the implementation of guided inquiry. As outlined above (Table 2), the accomplishment of the curriculum-based learning targets indicated the engagement of the students in the inquiry-based task. My interest was to make statements about the following aspects:

- How self-dependent do the students (start to) work? (personal skills, feeling of autonomy)
- Which ideas and methodical ways do the students use to approach the task and to acquire knowledge? (methodological skills, feeling of competence)
- How do they communicate with each other about the subject? (subject-related social skills, feeling of social embeddedness)

These questions were directly related to the aims of the teaching unit (see Table 2) and led to the following multiply revised category system (Table 3, revision is indicated). Each category refers to one need defined by Deci and Ryan (2000). The better the indicators of each category can be observed, the higher the level of engagement of the students.

Finding positive manifestations of these categories would be interpreted as a clear sign of affective engagement in sustaining the learning activity as well as active participation.

In the next section, the results of the outlined case study are described and discussed in relation to the competences the teaching was focused on. The interpretation of the results forms a basis for reflection. Reflection-before-action is needed to adjust the planning of the next teaching unit according to the knowledge gained (Postholm, 2008).

Table 3 Category system of the case study

Category	Definition	Indicators
Self-dependence (personal skill)	This category describes the willingness to work autonomously on the learning task. The student participates in the collaborative problem-solving. He assumes responsibility for the working process and sustains with the task (Senatsverwaltung für Bildung Jugend und Sport Berlin 2005).	1.1 Lennard and Paul start to work on their own 1.2 If a student does not start to work, avoidance strategies are observable 1.3 Lennard and Paul participate in accordance with their individual abilities 1.4 Lennard and Paul have to be asked to participate 1.5 Lennard and Paul independently use the support system ~~1.6 The support system enables them to continue their work~~[a]
Ideas for problem-solving (methodological skill)	This category refers to the ideas that Lennard and Paul contribute self-motivated to solve the problem. The category focuses on the methodological skills (Kultusministerkonferenz, 2004).	2.1 Lennard and Paul develop ideas for an experimental design (in a team) ~~2.2 The ideas are realizable, eventually using the support system~~ ~~2.3 The teacher has to intervene to avoid frustration~~
Subject-related dialogues (social skill with reference to subject matter skills)	This category refers to the communication about the topic-related problem-solving conducted in a team. (Indicator 3.2 can only be coded if 3.1 has been)	3.1 Lennard and Paul communicate about the topic in their team, maybe using the support system 3.2 The communication is target oriented to further develop the process 3.3 Lennard and Paul do not communicate about the topic

[a] The canceled indicators show the revision process of the analysis. These indicators were not found in the data.

7 Results and Discussion

To provide an overview, the following graph shows the frequency of each indicator (see Table 3) being coded during the 90-minute videotaped phase “guided inquiry” (Fig. 2). Multiple coding was permitted so that the figures do not add up to 100 %.

Surprisingly, the students did not use the supplied support system at all. Instead they developed many ideas on the basis of their prior knowledge to solve the posed question of how fish can survive in a frozen lake. In this case, Lennard was the prime mover and contributed his relatively broad knowledge, although he usually hesitated or even refused to work on new challenges. He decided on the following way of approaching the posed question (Table 4):

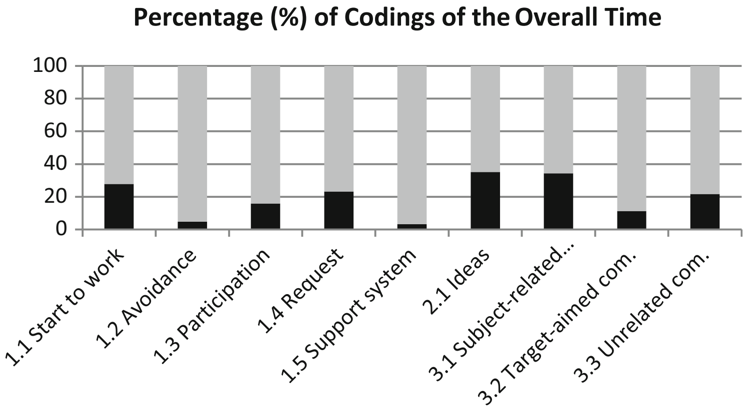

Fig. 2 Percentage of total time (90 min)

Table 4 Coding example 1

Category	Indicator
Ideas for problem-solving	2.1 Lennard and Paul develop ideas for an experimental design (in a team)
Teacher: Do you have an idea for an experiment to solve the problem? Lennard: Yes. (Puts his hand up.) Teacher: How? How can you show it? Lennard: We will take small paper chips. Teacher: Mhm. Lennard: Or we put those [paper chips] into the water; those are the fish then. Teacher: Aha. Lennard: We put ice on top and heat it at the bottom. Teacher: OK, do you want to install that? (Lennard nods and stands up.)	

My assumption was that Lennard was thinking about an experiment (Fig. 3) of the learning circle (phase 2 of the teaching unit) and thus used his prior knowledge without using box 2 of the support system (his file; see Fig. 1).

Additionally, Lennard came up with the idea to recreate fish, and for the ground of the lake, he used a red powder he found in the repository. He looked for materials on top of the provided material table. More generally, Lennard conducted a comparatively complex experiment of his own devising and was highly focused. Concerning the affective dimension focused on in my study, he seemed to participate very actively, and no fear of this new challenge was perceptible. In view of his usual, quite emotional way of approaching or rather avoiding new tasks, this was a remarkable change in his behavior.

Paul also showed a notable change regarding his engagement. At the beginning of this unit he struggled with being videotaped, showing highly defensive and aggressive behavior—although he was actually used to being recorded from earlier situations. But after a while of just observing, he began to join Lennard on his own impulse. He was very supportive and accepted Lennard as idea provider, although he himself usually was the one calling the shots. This was an impressive change

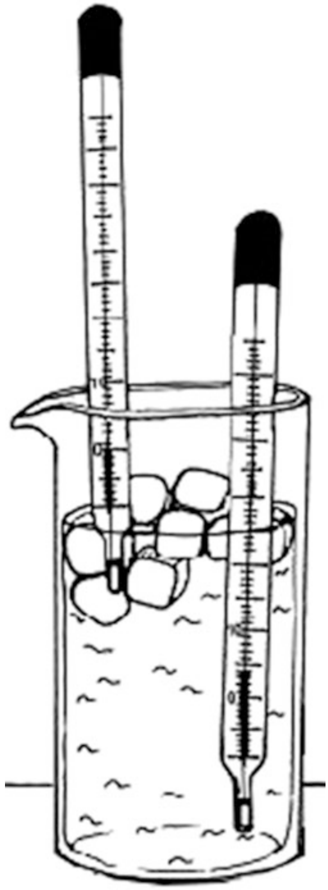

Fig. 3 Experimental task (outtake) of the learning circle (cp. Nové, 2000)

Table 5 Coding example 2

Category	Indicator
Self-dependence	1.1 Lennard and Paul start to work on their own
Paul: Lennard, what are you doing? Lennard: Installing the experiment. Paul: Ok. What else do you need? Do you need [a] candle?	

from his former behavior, where he often tried to be cool and to distract everyone from working (Table 5).

Even in situations when Lennard behaved in a highly authoritarian manner and could not share responsibility, Paul remained calm and conciliatory (Table 6).

Moreover, Paul showed that he comprehended the given task by appropriately naming many of the technical terms he had learned during the phase of structured inquiry. He realized that he could contribute his prior knowledge to the problem-

Table 6 Coding example 3

Category	Indicator
Self-dependence	1.3 Lennard and Paul participate in accordance with their individual abilities
Lennard: Now stir. Stir! Paul: No. Lennard: Stir. Stir![a] Paul: For that we take, Ms. Abels, do you have something to stir that? Lennard: To stir. (Relaxed.)	

[a]Emphasized words are underlined.

solving. He also formulated assumptions without help. Thus he showed a level of language proficiency I had not seen in him before.

Both students discussed their proceeding without conflict. More subject-related argumentation was noticeable than unrelated chitchat. Thus, a high level of engagement and sustaining the task was observable. Never before had I seen them with this level of active participation, self-dependence and enthusiasm, and hardly any refusal despite being confronted with a new challenge.

It was very enlightening to see how the students worked on the basis of their prior knowledge and conceptions like the following example illustrates.

Paul	There is, they sink, they [the paper chips] sink. One is sinking.
Teacher	Oh yes, cool.
Lennard	Yes, because of the heat.
Teacher	Well, why because of the heat?
Paul	They all want to get to the heat.
	(. . .)
Teacher	Why do we know that it is warm down there?
Lennard	Because the paper chips are sinking.

The questions I asked led to the explication of the students' conceptions. The outtakes of the video helped me as a teacher to take up subject matter issues in subsequent lessons without much interruption of the immediate situation, which might have reduced their level of engagement.

A scene like the one above could also be a starting point for the students to develop further questions and thus do coupled inquiry, i.e., to develop an open-inquiry task based on a previous guided one (Martin-Hansen, 2002).

In summary, the results indicate in favor for the hypothesis that guided inquiry was appropriate to increase engagement and active participation concerning the students' science learning. During the phase of experimenting, it became obvious that, at certain points, the students needed more scaffolding or reworking of their subject matter knowledge. But in terms of their emotional condition to approach the task methodically and collaboratively, the students handled the implementation of inquiry enormously well. This was indicated by their immediate and pertinent ideas to answer the given question (competence), their level of independence (autonomy), and their issue-related conflict-free dialogues (relatedness and competence). This was interpreted as basic engagement. "The positive development of their individual pre-conditions was [evidence] positive for me that implementing guided inquiry successively was well worth doing" (Abels, 2012, p. 170f).

In the following the results will be described more detailed in relation to the three main categories of the analysis: self-dependence, ideas for problem-solving, and subject-related dialogues.

7.1 Results of the Contentual Structuration

7.1.1 Self-Dependence

The students impressed me enormously with their degree of self-dependence in the phases of planning and conducting an experiment. They started working on the task on their own initiative and also worked mostly without being asked during the process. The requests for students' participation I coded mostly (indicator 1.4) refer to the phase of minute keeping or took place after unrelated communication. Overall, the learners showed an enormous willingness to solve the problem. On the basis of their usual behavior (avoidance, refusal, aggression, etc.), this was not to be expected.

Hence, the self-regulated learning process was indicated by a low amount of teacher guidance during the carrying out of the experiment. If any, I asked open questions to outline the task or to make the students think out loud and state their beliefs as I was interested in their conceptions.

Another indicator for self-regulated learning was that the students did not use the supplied multistage support system (see Fig. 1) apart from the material table where materials were suggested that could be used for all four questions posed in the beginning. The students had to choose the proper material for their question, but they also asked for other devices and for permission to search the repository. In other words, the students almost exclusively relied on their own ideas. This self-dependent acting also supports my hypothesis about the engagement in inquiry learning. The students managed to do the phases of planning and conducting an experiment without showing avoidance strategies. It seemed to be an optimal challenge for them and a relevant activity.

7.1.2 Ideas for Problem-Solving

As outlined before, Lennard was the initiator with his ideas about how to solve the problem. As I had to be alert to refusal, this immediate creativity was surprising. He suggested his ideas and installed the experiment together with Paul. During that process they discussed and deliberated problems collaboratively and without arguing. They were on eye level and shared their ideas. In teamwork they found solutions. The students participated in the problem-solving on the basis of their prior knowledge.

Lennard	Ey, we did something wrong.
Paul	Why?

Lennard	They [the paper chips] do not sink. They are not pushed down.
	(Paul takes the beaker and wants to put a lot of ice into the water with the "fish.")
Lennard	Eh de de. That is too much water for now.
Paul	Strain a little bit off, at least to the 300, where it says 300 or 200, 50. To the 250, ok?

Over time the installation of the experiment gained complexity and was increasingly focused on answering the question. However, in the beginning the students did not think about the documentation of their observations. They forgot to measure the different temperatures so that I had to intervene.

Teacher	How can we show that it is warmer down there?
Lennard	By watching.
Paul	By touching.
	(. . .)
Teacher	Better don't. What can you use to find out //
Lennard	At the top it is cold.
Teacher	And what can you use to find that out?
Lennard	Heat.
Paul	A:::, I know it, don't say it.[5]
Teacher	I don't say it.
Paul	I know it, I know it. I think this is an experiment. (Reaches for a thermometer.)

This scene illustrates once more that the students managed the methodical procedure and social part of inquiry, but that they struggled with aspects that can be ascribed to the competence area "subject matter". Although they had the opportunity to develop knowledge during the learning circle they were not able to transfer the knowledge. For students with a focal point on support in learning, transfer is a highly relevant demand. I decided to take up some subject matter aspects they mentioned in small steps once they had conducted the experiment so that their need of competence could be satisfied. The two learners should feel approved in their behavior. The decision to focus more on the affective dimensions in this lesson instead of on the concurrency of affective and cognitive aspects was made to avoid mental overload and frustration.

7.1.3 Subject-Related Dialogues

During the implementation of guided inquiry, the learners showed a high competence level concerning communicative and cooperative skills. The students led issue-related discussions especially during the phases of planning and conducting the experiment. Unrelated communication did occur, but it did not result in excessive distraction or even fights, which had happened before. The students helped each other to refocus and to solve difficulties. Thus, they could negotiate their

[5] Colons show that Paul drawls.

course of action without a lot of support on my part. Furthermore, their levels of concentration and persistence with the task were remarkable.

Conclusively, the findings in these categories show how the students' engagement to work on a task persistently increased in comparison to the science lessons before. More active participation and related behavioral strategies could be observed.

Implications derived from this case study for the affective dimensions of chemistry education as well as limitations will be addressed in the next section.

8 Conclusions and Limitations

The following section deals with the reflection-on-action and reflection-before-action in order to evaluate and revise the knowledge gained for further implementation so that the action research cycle could start again.

The case study has revealed that it is reasonable to adjust teaching practice to the affective preconditions of special-needs students with focal points of support in learning and emotional and social development to reach active participation and engagement in chemistry learning. The results are in line with the recommendations of Lynch et al. (2005). From my point of view, it would have hardly been possible to engage students in working on a scientific task if their affective situation had not been considered. In accordance with the complexity of the learners' emotional situation and experiences, aims, approaches and methods of teaching, scaffolding, etc., were chosen and adapted. Like the study of Maria et al., this study revealed that "constant re-evaluation of the strategies used by the teacher" is demanded "to guarantee an affective proximity between students and school chemistry" (2003, p. 1109).

Furthermore, it was helpful to reduce cognitive demands while implementing a new approach, especially as defensive strategies and fear of failure were expected. The students could hardly handle high demands in cognitive and affective domains concurrently, although both are relevant depending on objective, topic, and method to be implemented. This implies that aims in the two different domains should be strived for consecutively to avoid mental overload and frustration.

Here, inquiry-based learning has turned out to be an appropriate approach in terms of influencing affective aspects, with the limitations that inquiry-based learning has to be implemented successively and carefully scaffolded. Villanueva et al. (2012) corroborate this finding. The skills needed to manage an inquiry are multidimensional and challenging. Taking time to launch the respective subject matter and social, personal, and methodological skills is necessary to reach at least level 2 (guided inquiry), which may be the optimal level for some students (Blanchard et al., 2010; Scruggs & Mastropieri, 2007). Applying a well-conceived inquiry-based approach and thereby orientating to the students' needs "causes more engagement, more motivation, more self-confidence and a greater competence gain for all participants—pupils and teacher" (Abels, 2012, p. 171). And that makes the implementation worth it.

However, like Lloyd (2010, p. 126) says, "the evidence produced by the case study is entirely qualitative, limited and very subjective." Nevertheless, the data is rich and allows deep insight into the learning and behavior of two special-needs students. These details are rarely mentioned in research papers and leave the implementation of inquiry-based learning nontransparent. Further research should extend the time of video recordings and observe more students in special and inclusive settings. Furthermore, older students learning more complex concepts of chemistry should be researched.

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Affect and Meeting the Needs of the Gifted Chemistry Learner: Providing Intellectual Challenge to Engage Students in Enjoyable Learning

Keith S. Taber

Abstract Meeting the needs of gifted learners is normally considered from a cognitive perspective—a matter of incorporating sufficient higher-order cognitive tasks in learning activities. A major problem in the education of gifted learners is lack of challenge, which is needed to ensure such students are able to make progress. Lack of challenge can also influence learner motivation and even lead to boredom. Meeting the needs of gifted learners is therefore a matter of matching task demand to their abilities to meet their emotional as well as their cognitive needs. The present chapter suggests that an aim in teaching should be to engage learners in activities that offer an experience of 'flow', which is achieved when learning demands offer sufficient but not insurmountable challenge. Flow is an inherently motivating experience but requires a suitably high level of task demand to maintain deep engagement. The chapter draws on an example of a science enrichment programme that offered activities that were demanding for the 14–15-year-old learners because they drew upon cognitively challenging themes (related to aspects of the nature of science) and required a high level of self- (or peer) regulation of learning to provide high task demand. An example of one of the activities concerning the role of models in chemistry is described. Students recognised that learning activities offered greater complexity, open-endedness and scope for independent learning than their usual school science lessons. The features that students reported in their feedback as making the work more challenging also tended to be those they identified as making the activities enjoyable.

Keywords Gifted • Affective domain • Flow • Metacognition • ASCEND project • Nature of models in chemistry

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1 Introduction

It is widely accepted that 'gifted' learners can be considered to have 'special needs', even when giftedness is understood as simply being at one end of a normal distribution of ability, intelligence or achievement (Reis & Renzulli, 2010). From a cognitive perspective, students who are more advanced in their knowledge and understanding of a subject clearly need to be offered teaching that allows them to develop further conceptually and which is therefore often likely to be too demanding for many of their less gifted peers. From an equal-opportunity standpoint, all learners should have opportunities to develop towards their full potential. From an economic or policy perspective, it is important that the most able are enabled to meet their potential, as that potential can be understood as a key societal resource (Subotnik, Olszewski-Kubilius, & Worrell, 2011). That is, many of the creative scientists and other significant contributors to a society are likely to have been gifted learners who were supported to develop their potential. So from these perspectives, it is important that gifted learners are suitably challenged in their education. The present chapter however puts a particular focus on the learner experience and considers how chemistry teaching can provide an intellectually *satisfying* experience for the most able learners.

1.1 Educational Experiences of Gifted Learners

Given the diversity of educational provision across different national contexts, it is not appropriate to generalise about the nature of gifted learners' experiences in school or even in a single school subject such as chemistry. However, there has long been a concern that when educational provision does not sufficiently take into account the needs of gifted learners, there is a danger of them achieving much less than their potential.

In particular, learning activities that do not offer a gifted learner sufficient challenge can damage the students' motivation to study and lead to boredom (Gallagher, Harradine, & Coleman, 1997; Phillips & Lindsay, 2006) and even frustration (Keating & Stanley, 1972) and disengagement (Kanevsky & Keighley, 2003) with school classes. Gifted learners in regular classes may face emotional problems 'because of a mismatch with educational environments that are not responsive to the pace and level of gifted students' learning and thinking' (Reis & Renzulli, 2004: 119). Most of us, gifted or otherwise, have sat through occasional presentations in an academic or professional context where we felt that we were learning nothing, that the material was being oversimplified, that the style of presentation was condescending and most of all that we were wasting valuable time. Some gifted learners in some classrooms may experience most instruction to be of that type.

Kanevsky and Keighley (2003) consider that learning can act as an antidote to the emotion of boredom in gifted learners. In other words, when we feel we are genuinely learning something and recognise that we need to commit our concentration to do so, we are engaged and consider we are involved in purposeful and worthwhile activity.

1.2 What Is Giftedness?

Giftedness and high ability are understood differently in different national educational contexts (Cropley & Dehn, 1996). So some work on giftedness is focused only on those who have demonstrated extremely high attainment, whilst elsewhere (in the English national context, considered below, for example) it simply means the top 5–10 % of students (however judged) in any ability group (Taber, 2012). There are different approaches to how giftedness is best understood and identified (Sternberg & Davidson, 1986; Taber, 2007c), for example, about the extent to which it is determined by genetic factors or can be nurtured through educational experiences. There are questions over whether giftedness describes a person or needs to be understood contextually, i.e. that a person is only considered gifted in the context of certain activities that are evaluated in terms of particular norms and expectations (Sternberg, 1993).

These are important issues, but detailed consideration of them is outside the scope of the present chapter. So for the purposes of the present account, giftedness will be defined in a pragmatic way that relates to the concerns of teachers and others charged with established curriculum or educational provision.

The premises of the present chapter are that:

1. In any teaching group, learners are likely to vary across a range of characteristics, including:
   (a) The extent of their existing knowledge of the material to be learnt
   (b) Their prior learning of the prerequisite knowledge of what is to be learnt
   (c) The cognitive and metacognitive attributes available to support new learning
   (d) The predisposition to engage fully in learning
2. This variation may not be uniform across a teaching subject (such as chemistry): for example, some students will more readily learn new conceptual material; some will enjoy practical work more than others; some will have particular strengths (or limitations) in applying mathematics in the subject; students may have uneven prior knowledge (stronger in some topics than others within a subject), with differences among a teaching group, etc.
3. Effective teaching will be pitched at a level that challenges learners whilst supporting achievement (see Chapter “Meeting Educational Objectives in the Affective and Cognitive Domains: Personal and Social Constructivist Perspectives on Enjoyment, Motivation and Learning Chemistry”).

From these starting points, we can recognise that in *any* class, undertaking *any* particular activity or studying *any* particular topic, a teacher will be undertaking 'mixed-ability' teaching and that the same teacher presentations and learning activities are unlikely to be *perceived* as of similar levels of difficulty by all those in a group. A pragmatic notion of who should be considered as gifted in any class would be the students who would not be suitably challenged by teaching that is pitched for the 'average' (median) student and so would not benefit from such teaching in terms of achieving substantive learning.

This is of course a relative or contextual definition in the sense that in the same class it may lead, for example, to different learners being seen as gifted in tomorrow's melting point determination than in today's lesson on the characteristics of the transition metals. The core issue here, how to differentiate teaching to meet the needs of all students, is just as relevant to those who will have special needs by being at either end of the distribution, as it is clearly important that teaching should be matched to the needs of *all* learners in a class. The focus of the present chapter is on the gifted (where the teacher needs to increase the level of challenge): but that is not intended to suggest that the needs of the lowest achievers (where the teacher needs to increase the level of support or 'scaffolding') are not also important.

2 Responding to the Needs of the Gifted

There are various general approaches that can be used to address the needs of gifted learners, but all have limitations (Rogers, 2007; Stepanek, 1999). A well-established approach in some educational/institutional systems is setting or streaming. Streaming involves identifying students in different general ability bands and organising classes accordingly. The top stream will be taught all or some of the different subjects in the curriculum as a class, whilst perhaps being in mixed-ability groups for some other subjects, or for pastoral sessions. Setting is subject specific, with students grouped according to perceived ability in a particular subject.

There is an ongoing and sometimes vigorous debate in educational circles (e.g. Boaler, Wiliam, & Brown, 2000) about whether such approaches are (a) effective (overall or for particular ability groups) and (b) fair or desirable on other grounds. This is not the place to engage in such issues in any detail; however, one particular concern is that once students are identified as being in a particular band or set, it may become difficult for them to be promoted into a 'higher' group as over time the additional, or distinct, work completed by the top band or sets will make transfer into those groups difficult—even for a student who is achieving at a very high level in another class that is completing less, or less demanding, work.

This is an important consideration because it is easier to identify current levels of attainment than potential for future achievement, and so a student working below potential may lose the option to engage more fully once they are assigned to a set or stream where the work does not challenge them. Moreover, intellectual development is not an even process and does not occur at the same rate in all learners. An apparently average student may suddenly start to show higher levels of ability, especially so for adolescents who are undergoing major hormone-moderated changes (Ramsden et al., 2011).

These arguments aside, as pointed out above, a subject like chemistry involves a wide range of intellectual and other skills, and even subject-specific setting has to be based on typical levels of performance (or a prioritisation of some skills/abilities being seen as more significant than others) when some students show very uneven profiles across a subject. Even a skill such as problem-solving in science may depend upon a range of cognitive skills/variables (Stamovlasis & Tsaparlis, 2003). It is also possible that as a subject changes over time (and chemistry certainly becomes more abstract and conceptually sophisticated through secondary and college education), it may start to better suit different students.

There is also the difficult issue of meeting the needs of the so-called twice-exceptional learners (Sumida, 2010; Winstanley, 2007)—students who may show exceptional potential in some regards, whilst also having learning difficulties, or even difficulties in such basic skills as producing speedy and accurate handwriting (Montgomery, 2003). So, for example, students who are highly able and conceptually very 'sharp' yet have specific learning difficulties that compromise their writing abilities may struggle to produce acceptable written work, whilst shining in classroom discussion. Most school chemistry teachers will have come across students who fit this description—students who seem engaged and full of ideas and who ask perceptive questions but who are unable to produce written work that reflects this. (Such students are less common in college-level chemistry classes—simply because of the usual ways we formally assess student achievement and filter those offered admission to further and higher education.)

These arguments suggest that streaming or setting may not be an ideal solution, and of course in some educational contexts (e.g. schools in very rural settings, classes in many school 'sixth forms', for example), there is only one class taking a subject at any level, so such an option is not available. It is also clear that setting will only reduce (and not eliminate) the range of levels of attainment of the students in the class. When considering 'top sets' (or streams), the issue can be more extreme because of the nature of distributions: in many educational contexts, a top set will include students of modest ability but high motivation and engagement, alongside the students of very high, and sometimes extremely high, achievement in the subject, who are found on the tail of the distribution.

In some national contexts, it is not unusual to promote particularly advanced students to a cohort that is essentially comprised of an older age group: but this may have complications, both in terms of social cohesion and what happens when the student reaches the 'end' of the system early (e.g. completing school before a legal school-leaving age). Another strategy is to offer something additional (enrichment, such as the in the project discussed below) to supplement the core curriculum. If this is done outside of normal timetabled sessions, it may well have some benefits, but again there are potential problems. One is of equity—should the most able be offered *more* (rather than different) education and access to learning resources than other learners—who arguably need access to educational resources at least as much? It may also be the case that the additional enrichment activities can be seen by gifted learners as challenging and enjoyable, highlighting just how pedestrian the compulsory core classes seem (certainly an issue suggested in the project discussed below). They may wonder why they have to give up some of their own time to experience chemistry teaching that excites and challenges them. Enrichment activities should not therefore be seen as compensating for undemanding learning experiences in regular chemistry classes. That is not an argument for avoiding suitable enrichment activities, such as chemistry 'Olympiads', for those students who are suitable and keen to be involved: however such optional extras do not negate the need for *all* learners to be suitably challenged in their standard curriculum sessions.

2.1 Optimal Levels of Challenge When Teaching Gifted Learners

A key feature of effective teaching is tuning the level of demand of tasks to match the learners (see Chapter "Meeting Educational Objectives in the Affective and Cognitive Domains: Personal and Social Constructivist Perspectives on Enjoyment, Motivation and Learning Chemistry"). It has been suggested that student learning experience can be characterised in terms of how task demand matches student skill level (Nakamura, 1988). When a task makes high demands that are matched by high levels of skill, students can potentially engage productively and experience what has been termed 'flow' (Csikszentmihalyi, 1997)—a high level of engagement in an activity. When students feel they are being successful in responding to what they recognise as challenges in their learning, they are more likely to experience learning as a positive—rewarding and worthwhile—activity that makes them feel good about themselves (see Fig. 1). Similarly, there is potential for learners who regularly experience failure in the face of such perceived challenges to doubt their ability and find learning a negative experience. This is a general argument that applies to all learners, whether gifted in chemistry, more typical, or struggling in the subject. The particular issue with gifted learners is that work which offers optimal challenge to many of their peers offers little to stretch their thinking and tempt them out of their comfort zone—their 'zone of actual development' (Vygotsky, 1978)—where drill may improve accuracy and speed but does little to develop their thinking or skills.

2.2 Higher Levels of Intellectual Development

To consider how the teacher should design learning activities to offer optimal challenge for the most able learners, it is useful to consider some ideas about the nature of intellectual development. Bloom's taxonomies (Bloom, 1968; Krathwohl, Bloom, & Masia, 1968) can offer some guidance here, but especially when

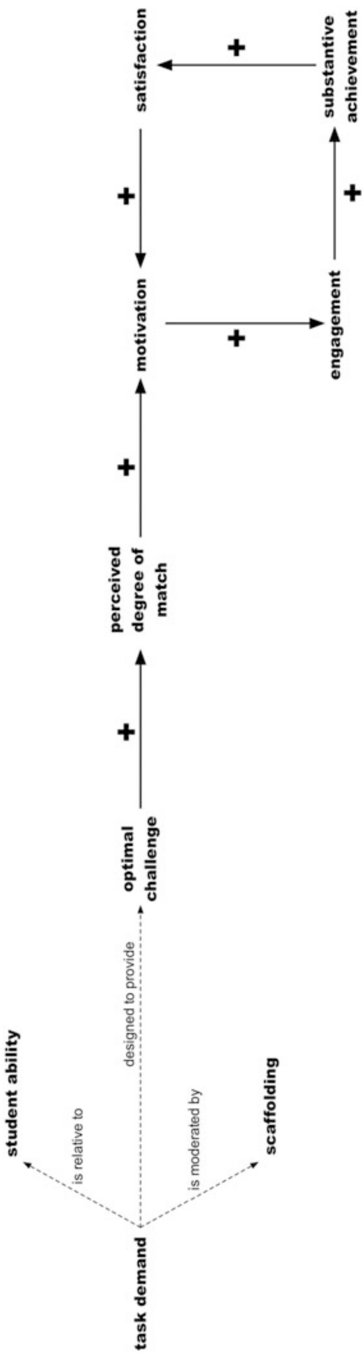

Fig. 1 Optimising the level of task challenge can engage learners as well as support learning (see Chapter "Getting involved: Context-based learning in chemistry education")

considered in relation to the work of Perry (1970) on the intellectual and moral development of college students.

Bloom's (1968) taxonomy of educational objectives in the cognitive domain is often used as a tool to consider the demand of learning activities (Anderson & Krathwohl, 2001), and teachers are aware of the importance of setting work requiring 'higher-order' cognitive skills, such as analysis, synthesis and evaluation—especially when working with more advanced learners (Taber, 2007c). The parallel taxonomy of educational objectives in the affective domain (Krathwohl et al., 1968) is less commonly referred to. The five major categories in the taxonomy are 'receiving', 'responding', 'valuing', 'organisation' and 'characterisation by a value or value context', each of which is divided into subcategories.

The highest level of the typology was labelled as 'characterisation by a value or value complex'. Characterisation here refers to how *the individual* can be characterised, because they have an internalised set of values that consistently informs their actions. This was divided into two sublevels. The first is called 'generalised set' which was said to provide 'an internal consistency to the system of attitudes and values at any particular moment' providing a 'predisposition' to behave in particular ways (Krathwohl et al., 1968: 48). Bloom and colleagues considered this to provide a 'basic orientation which enables the individual to reduce and order the complex world about him [sic], and to act consistently and effectively in it' (p. 48). The focus on complexity relates to an ability to make judgements in consideration of 'situations, issues, purposes and consequences' when it was not sufficient or appropriate to follow simple rules. Finally, the highest sublevel or 'characterisation' concerns developing a consistent philosophy of life—a worldview that would encompass all domains within its range of application.

2.3 The Development of a System of Personal Values

Arguably, Bloom's scheme for the affective domain is more difficult to operationalise in teaching than the taxonomy in the cognitive domain. However, it should be noted that the high-level cognitive skill of 'evaluation' involves making judgements against some set of values or other, and such judgements will be more consistent where the individual has developed their own coherent set of values (i.e. the highest level of educational objectives in the affective domain), suggesting strong links between these two domains.

Following Piaget (1970/1972), cognitive development is often seen to lead to formal operations that are commonly attained during adolescence. However, a number of observers have argued that formal operations are not the end point of cognitive development, which needs to proceed to allow people to cope with the complexity of real-life scenarios where problems are often undetermined by available data and where it is not possible to adjudicate between competing perspectives simply on logical grounds alone (Arlin, 1975; Kramer, 1983).

Whilst chemistry teaching has traditionally concerned itself largely with setting learners well-defined tasks, school and college science teaching increasingly includes consideration of socio-scientific issues which require more than simple logical application of concepts (Sadler, 2011; Sheardy, 2010). Arguably such activities offer particular potential to challenge gifted learners (Levinson, 2007), who may spontaneously raise questions about such issues (Tirri, Tolppanen, Aksela, & Kuusisto, 2012).

Of relevance here is the work of Perry (1970), who explored intellectual and ethical development of students attending the prestigious undergraduate colleges of Harvard and Radcliffe. Perry developed a scheme to describe the stages through which learners passed, something akin to the Piagetian stages of cognitive development (Piaget, 1970/1972). Perry was not the only person who explored aspects of moral development, and indeed Lawrence Kohlberg's (Kohlberg & Hersh, 1977) scheme is probably more widely known. However, Perry's scheme did not seek to separate development of intellect from development of a personal value system. Moreover, some of Perry's key findings can be considered to be of particular relevance to science/chemistry education (Finster, 1989, 1991). Perry's scheme, unlike the better known work of Piaget, did not exclude individuals from sometimes taking retrograde steps in relation to the hierarchy of levels or stages, and this reflects longitudinal research into the development of moral motivation which suggests a *general* trend towards greater degrees of moral motivation but with some *individuals* actually presenting downward shifts between measurement points (Nunner-Winkler, 2007).

In particular, Perry found that adolescents and young adults seem to commonly pass through an intellectual journey away from a sort of absolutism, through a relativist phase towards a more sophisticated stage when value judgements can be made in nuanced ways. Perry's original work is quite detailed, offering nine stages, but for present purposes, this simple three-stage simplification reflects this key issue. In caricature, then, Perry found that on starting college new students often expected their teachers to be a source of absolute knowledge and to refer them towards authorities that were considered to be correct. Instead, their teachers often directed them to diverse and apparently conflicting sources that offered opposing views (especially in the humanities and social sciences). The initial response to this was a shift from seeing knowledge in terms of truth to being a matter of opinion, i.e. different people have different opinions, and in education we learn about these different opinions, and perhaps we choose the opinion we wish to hold whilst recognising it is just that—an opinion. In this 'relativist' stage, there can be no arbiter of truth or right, because it all comes down to different people holding different opinions—and everyone is *entitled* to an opinion.

Students could (sometimes slowly) move beyond this naive relativism to come to understand that even if we can no longer aspire to simple absolute knowledge, we can still form judgements that are principled and argued from a coherent position. So the final stages of this process, which Perry suggested even very able students might not complete during their undergraduate years, link to the highest level of the taxonomy of educational objectives in the affective domain, with its focus on personal values that the individual has characterised and organised into a coherent system.

2.4 Intellectual Challenges in Learning Science

Notions that science unproblematically uncovers how the world is, leading to scientific truths that can be considered absolute knowledge, are now generally seen as naïve. Kuhn's (1996) highly influential model of how science has progressed highlights the role of such extralogical factors as culture, advocacy, tradition and social organisation—and for some opened up the question of to what extent science is itself just a culturally relative form of knowledge—an issue that has become a major focus of attention in the philosophy of science (Laudan, 1990; Rorty, 1991). Kuhn himself did not consider science to be culturally relative in an extreme sense (that the true nature of the natural world depends upon where and when you want to know), but rather acknowledged the genuine issue of whether humans could make truly objective judgements that rose above their culture (Kuhn, 1973/1977). Arguably, even if human intellect allows us to recognise the nature of our own conceptual frameworks, and the possibility of entertaining alternative ways of thinking (Popper, 1994), the essence of being human is such that we can never completely step outside the culture in which we have been socialised (Geertz, 1973/2000), so as to make fully objective judgements.

Such issues are not just of academic interest to educators, when the question of how scientists come to know is a core part of science education (Hodson, 2009; Matthews, 1994). A post-positivist view of science (Taber, 2009b) sees it as a complex activity where judgements made cannot be based purely on logical application of formal operational thought.

The first of Perry's three general stages will be familiar to many chemistry teachers. Students accept what they are taught in science as absolute truth, i.e. this is what scientists have found out—what they have 'proved' by doing experiments. Perhaps that does not matter as long as what they are learning is that sodium is a metal, that the formula of sulphuric acid is H_2SO_4 and that in solution chlorine will displace iodine from its compounds.

However, the science that gets attention in society—and increasingly in science classes (Sadler, 2011)—is often not the material that has long become part of canonical scientific knowledge but rather the more controversial topics where either (1) scientific debate continues or (2) sociocultural considerations have to be considered when deciding *how (or whether) to apply* the science. The science behind nuclear power stations is generally non-contentious, but how to weigh up the risks and benefits is less clear-cut. There is a widespread consensus that the climate is changing—but scientists do not all seem to agree on how quickly, how much is due to human activity and how serious the consequences will be. Evolution by natural selection is the foundation of modern biology—yet there are many aspects of evolutionary theory where vigorous debate continues (something seized upon by those who reject evolution and wish to characterise natural selection as 'just' a theory).

Perry's work warns us that once students accept that absolute knowledge is just an ideal and that education does not provide ready access to 'truths', the natural next step is to consider all areas where there is any kind of dispute as simply matters of opinion or little more than personal taste. Different scientists have different opinions on climate change, nuclear power and evolution: and they are all entitled to their opinions—just as the student or member of the public is entitled to an opinion.

That is not the kind of understanding of the nature of science that can productively inform future citizens in making science-related decisions (Sheardy, 2010). Rather, learners must both appreciate how scientific knowledge can become robust and trustworthy (without being beyond further question)—and so how our understanding of some scientific issues is still far from that stage—and how sometimes decisions about the applications of scientific knowledge can only be made by drawing upon values that are external to science itself (Sadler, 2011).

Science can tell us the potential risks of building a nuclear power station—but it cannot tell us what level of risk *should* be considered acceptable. Similarly, science can offer us an extensive evidence base for accepting natural selection, but it cannot tell us whether such acceptance is worth the risk of alienating friends and family when such ideas are considered to challenge the shared commitments making up a worldview for our community (Long, 2011). This example reminds us that although from a personal constructivist perspective (see Chapter "Meeting Educational Objectives in the Affective and Cognitive Domains: Personal and Social Constructivist Perspectives on Enjoyment, Motivation and Learning Chemistry") we might consider when evidence should logically lead us to change our mind (Posner, Strike, Hewson, & Gertzog, 1982), this has to be understood in the wider context in which learning occurs: the drive to a more integrated, efficient, explanatory framework with wider application is not the *only* motivating factor in learning (Pintrich, Marx, & Boyle, 1993).

2.5 Inherent Challenges in Learning Chemistry

Where in science education more generally we might recognise the need to apply values external to science in considering the social implications of science, the nature of chemistry is arguably such that the issues raised by Perry's work impinge significantly upon the learning of the science itself. Chemists and chemistry teachers often like to characterise the subject as a 'practical' or empirical subject, and indeed it is: but it is *also a theoretical subject* and in particular one that is understood and taught with a wide range of models.

For one thing, although chemistry underpins materials science, chemistry itself is largely developed by the rather severe abstraction of being about substances. Very few everyday materials are pure samples of substances, and only a limited number of the millions of substances known to (and indeed often created by) chemists are familiar to most young people from their everyday experience outside the laboratory. Moreover, learning about even a tiny fraction of the vast number of substances that *are* known is only made manageable by a range of categories and typologies used to organise chemical knowledge. Some of these categories and classes may be considered quite close to natural classes—the elements for example. But others are more arbitrary or less distinct. Notions of which elements are metals and which are nonmetals admit matters of degree. Categories such as acid and oxidising agent are, to a large extent, classes of convenience, as evidenced by the way chemists have been prepared to redefine membership based on new theoretical approaches (and the availability of new reagents, such as superacids). This is inherent in the abstract and complex nature of chemistry as a subject to be taught and learnt.

The various descriptions of substance properties and behaviours observed in the laboratory that make up the ‘natural history’ of chemistry at the macroscopic-theoretical-descriptive level are to a large extent underpinned in modern chemistry by explanatory models of the structure of matter at a scale far too small for direct perception (Johnstone, 1982). So students are taught about molecules and ions, about bonds and partial charges, about orbitals and electron clouds, about shifts in electron density and about the expansion of octets and resonance structures and hyperconjugation. Not all of this material is taught at once, and some is considered more advanced, but there is a brave new world of submicroscopic particles with their properties and behaviours to be imagined and understood and then to be used as theoretical tools in building explanations about the formal descriptions (changes of state, oxidations, precipitations, etc.) that are already one step removed from the flashes and bangs and colour changes and smells which are the actual phenomena directly available to learners (Taber, 2013).

Aspects of this account are well recognised. Johnstone (1982, 1991) long ago raised the issue of how new learners can suffer from information overload in being asked to deal with the macroscopic and submicroscopic levels and the various forms of symbolic representations used to think and talk about them. Moreover, work in the Piagetian tradition highlighted how the abstract theoretical nature of much in the secondary school curriculum did not seem to be aligned with the levels of cognitive development of many learners of secondary school age (Shayer & Adey, 1981).

However, Perry’s work suggests there is another issue, related to the *multiplicity* of much of what is set out as target knowledge to be learnt in chemistry. This has been described as ‘model confusion’ (Carr, 1984), but it has not had the attention it perhaps deserves as a major issue in teaching chemistry. Carr referred, for example, to the issue that there are several models, and so definitions, of acids, that appear in school and college curricula. In part this is a historical issue; as chemists make new discoveries and propose new ideas, which can be tested empirically, they refine their theories (Lakatos, 1970): yet in education such historical models are often presented ahistorically, and indeed what gets presented is sometimes a hybrid curricular model that is not true to any of the historical scientific models (Justi & Gilbert, 2000).

However, this is not the whole story, for in chemistry we often retain and continue to apply models that are less sophisticated even when newer models (so to speak) become available, because the simpler/older models are still considered to have a valid range of application and to be useful tools in our theoretical toolkit, fit for some purposes (Sánchez Gómez & Martín, 2003; Taber, 1995). We still use Brønsted-Lowry and Lewis definitions of acids, depending upon context. We model molecules as perfectly elastic spheres for some purposes, and yet as fuzzy irregular complex field patterns capable of superposition, for other purposes. We might describe the bond in water as covalent one day and yet polar another. We still explain some things in terms of a model of the atom as having concentric shells of electrons, whilst for other purposes we consider such a notion inadequate.

This is both an opportunity and a challenge (Taber, 2010a). The challenge is that students struggle to make sense of how a science that is meant to offer truth contradicts itself from day to day. For example, a student I interviewed over an extended period (Taber, 2000, 2001, 2003) suggested that the concepts taught in college chemistry seemed so different from school chemistry that having studied the subject at school interfered with studying the subject at the next level:

> If I hadn't have done chemistry G.C.S.E. [i.e. at secondary school level], in some aspects, some aspects of chemistry G.C.S.E., I would have found this [college level chemistry course] like easier to understand maybe, because like what they taught us at G.C.S.E. and what they teach us now like contradicts, as it were, and like it's harder for you to understand, 'cause ... you have to learn this for this exam, and then you learn it and then you remember it, and then when I do this course, or when you teach me, or [another lecturer] teaches me, I always think of that thing that I learnt for G.C.S.E. and it sort of like clashes, therefore like it's harder to remember...when they tell you the exact opposite, well not the exact opposite, but not, not very close to the truth, then it can't really be developed because you have to think in a different way.

Students despair of having learnt one model, only then to be told it is not really like that, and they should learn this other model. Of course it is not really exactly like this model either as they *are models*, and that is the point that often does not get communicated: for we are teaching models, not absolute accounts of nature. The opportunity here is twofold. If we make more of an effort to teach chemistry as often about building, applying and critiquing models (Taber, 2010b), then chemistry offers an excellent basis for getting across something of the nature of science as both provisional, partial, open to reinterpretation, but still able to offer useful and sometimes robust knowledge. Moreover, we can ask students to engage with precisely the kinds of complex situations that Perry found students struggle to make sense of. If young people need time and contexts to shift from absolutism and past relativism to a more mature position of commitment based on a system of underlying values, then here is an opportunity to engage with and practise such ways of thinking—chemistry offers a suitable theatre for trying out these ways of thinking when what is at stake offers limited risk to self-esteem, or self image, or community identity than some other contexts.

2.6 The Importance of Metacognition in Experiencing Learning

It seems then that there are strong links between the cognitive and affective domains. Another area or domain of importance is metacognition, which relates to the ability of a person to be aware of, monitor and control their own cognitive functioning (Whitebread & Pino-Pasternak, 2010). Metacognitive development is related to the ability to become a ‘self-regulated’ learner, something that facilitates a commonly recognised educational aim of developing ‘independent’ learners (Meyer, Haywood, Sachdev, & Faraday, 2008). White and Mitchell (1994) argued that a focus on developing learners’ metacognition could contribute to both supporting desired conceptual change and improving learners’ attitudes to science learning. Research supports links between cognitive, metacognitive and affective factors in learning. For example, Aydin, Uzuntiryaki and Demirdöğen (2010) used structural equation monitoring to explore a model relating self-efficacy, anxiety, task value, cognitive strategies and metacognitive self-regulation. Among their sample of Turkish students who were studying or had studied some chemistry at university level, they found that ‘as students realise the value of the academic task and get intrinsically motivated, they are more likely to utilise higher order strategies leading to meaningful learning’ (pp. 63–64).

One approach to conceptualising the links between the metacognitive and other domains is represented in Fig. 2. This suggests that metacognitive development potentially links with cognitive development (which provides the basic cognitive skills to support metacognitive faculties and which can potentially be monitored metacognitively), conceptual development (as understanding of concepts can be monitored and evaluated, i.e. metacognitively) and affective development (as the development, application and systematicity/coherence of the individual’s values can be monitored and evaluated).

Metacognition may, for example, be important in allowing learners to ‘stand back’ from their ideas and beliefs and so, for example, appreciate the limitations of their alternative conceptions. The highest level of affective development (Krathwohl et al., 1968) involves acquiring a coherent set of values that can be applied systematically in life. Educational institutions would normally seek to guide learners on the values that should be adopted (e.g. fairness, compassion, etc.), and this might be considered to be more the remit of moral education or best facilitated by studying the humanities. However, science education certainly offers target values that it hopes learners will adopt into their personal value system, for example, values relating to the importance of evidence, objectivity, seeking consistency and being critical. Arguably such ‘scientific’ values are not always those that should take precedence in all contexts (e.g. there are occasions when it is more important to offer emotional support to a friend in distress than to seek to offer a critical objective analysis of their situation), but at the highest levels of the taxonomy of educational objectives in the affective domain, the individual has developed a system of values that allows judgements to be made about which

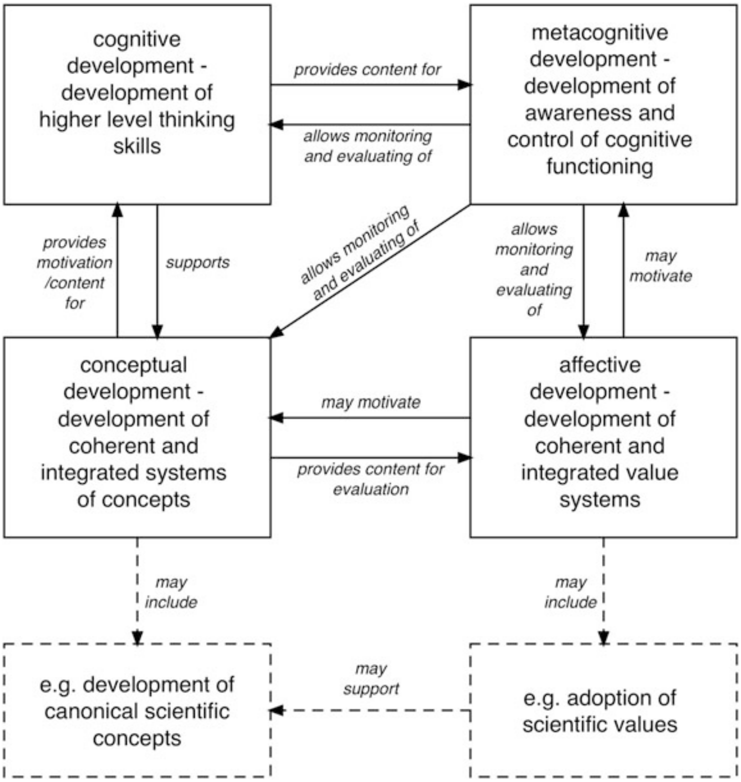

Fig. 2 The development of a system of values (in the affective domain) may motivate conceptual and metacognitive development

particular values take priority in particular contexts. A strongly developed system of values, including acceptance of the importance of scientific values in inquiring into the natural world, and a high level of metacognitive monitoring and control may be especially important when a learner is faced with science teaching inconsistent with their, and their peers', current conceptions in a topic (see the discussion in Chapter "Meeting Educational Objectives in the Affective and Cognitive Domains: Personal and Social Constructivist Perspectives on Enjoyment, Motivation and Learning Chemistry") and can potentially support the teacher's aim of bringing about desired conceptual change.

Developing metacognitive skills (just as with other areas of learning) depends upon learners being offered suitable challenges in their learning and so requires support from teachers (Postholm, 2010). Learners must be given opportunities to exercise substantive choices in their learning and then to monitor the effects of their decisions, if they are to practise and enhance their metacognitive skills and become self-regulated learners. Building some elements of choice into classroom activities offers opportunities for learners to make decisions and reflect upon the outcomes of those decisions and can be introduced with minimal risk to other learning outcomes and modest teacher effort. For example, in teaching high-achieving secondary-age students about the nature of scientific explanations, alternative choices of context were provided for some activities (Taber, 2007a). Simply offering small choices in this way helped give learners a sense that they had some control over and responsibility for learning activities. Clearly, teachers do not have the spare capacity to regularly build alternatives into all their lessons, but this case study suggested that providing a choice of alternative examples to work on enhanced the learning experience for a ‘top set’ of 13–14-year-old students.

It was suggested above that learners identified as gifted may show uneven profiles of developments, but in general it is likely that gifted learners have developed their metacognitive faculties further than most of their peers (Shore & Dover, 2004) and so are not only better positioned to respond to challenges to take more responsibility for their own learning but are arguably not being supported to develop their self-regulatory abilities *unless* challenged in this way, working in their zone of proximal (metacognitive) development. Some highly gifted learners may well have accepted that most classes they attend are not challenging to them and may have already developed high levels of ability as autodidacts—seeking out their own learning challenges outside of the formal curriculum. One strategy that may be useful when teaching such students is to involve them in peer tutoring as long as this is done in a way that allows the gifted learner to benefit as well as the peer being tutored. Teachers can draw on their own experience here and appreciate how the process of preparing to teach others demands high levels of metacognitive skills to identify and address shortcomings in one’s own subject knowledge, as well as pedagogic skills in making material accessible to others. In other words, asking the gifted learner to take on peer tutoring may be an ideal learning opportunity for *the tutor* as long as they are supported to understand and take on a pedagogic role (Taber, 2009a). Teachers sometimes ask how they are meant to teach the highly gifted learner whose own learning of the subject has outreached that of the teacher. The answer will sometimes be to teach that learner in an area where the teacher does have greater expertise as an educator. As teachers will appreciate, a well-prepared peer tutor can find the role highly engaging and satisfying—as well as suitably challenging.

3 Putting the Principles into Practice

This chapter has introduced a number of themes to consider in relation to supporting the learning of gifted learners. The remainder of the chapter discusses an example of an enrichment project (‘ASCEND’) which looked to supplement secondary science experiences for a group of students identified by their schools as likely to benefit from additional challenges related to science learning.

3.1 The ASCEND Project

The ASCEND (*Able Scientists Collectively Experiencing New Demands*) project was an after-school enrichment programme for 14–15-year-old students in Cambridge, England. State comprehensive schools nominated students they considered could benefit from experiencing challenging science activities. The programme involved seven sessions, each based around a different theme (Taber, 2007b).

In designing the programme, a number of principles were followed. Most of the activities were designed as small-group work, requiring group discussion, so that progress in tasks would require the students to explore and share their thinking. There was a deliberate attempt not to micro-supervise activities, such that once a session was set up, the groups were largely left to organise their own work. The programme was staffed by graduate students who were available for consultation but asked to only intervene when invited by a group to contribute.

This was in part an attempt to encourage the students to take more responsibility for planning and monitoring their work, because it was considered gifted learners should either have advanced metacognitive skills or at least have the potential to develop these skills; and the use of group work allowed the possibility of peers modelling the processes of monitoring and regulating learning activities within the groups. However, it was also in keeping with the intention to offer these adolescents, attending in their own free time, a taste of an adult learning experience. So the students were denoted as 'delegates' from their schools, and the sessions began with a conference-like registration with refreshments.

A main theme for much of the programme of activities was that of the nature of science. This was selected because of two sets of considerations. For one thing, the aim was to offer enrichment, rather than just teach material that would be met later in school (which might undermine later school learning), and yet to offer something clearly relevant to school science. The English national curriculum had an increasing emphasis on teaching about the nature of science (QCA, 2007) but it was recognised that this aspect was challenging for teachers (QCA, n.d.), and there was limited clarity over how this aspect of the curriculum should be taught.

The main reason for focusing on activities related to the nature of science was the potential to address a post-positivist view of science, where knowledge is never definitive and evidence is always open to other interpretations. Arguably this theme provides the ideal context to support development through the stages of intellectual and ethical development identified by Perry (1970). Science can be seen as being based upon the application of a well-established set of values (such as always considering evidence, looking for the consistency between different concepts and theories, seeking objectivity, etc.) to reach conclusions which can be seen as robust and trustworthy, even whilst accepting that one remains open to revisiting those conclusions in the face of new evidence. Science done well might be considered the personification of Perry's fully developed intellect on a collaborative scale.

3.2 A Chemistry-Based Activity

ASCEND was a science enrichment programme, which included activities related to various science themes. One of the activities was related specifically to chemistry learning. The 'nature of science' theme for the session was the nature of scientific models. There were two similarly structured activities to be completed, each asking students to offer explanations based around one or both of a pair of models.

The first activity related to two models of the nature of matter at the submicroscopic level. A core issue in teaching chemistry is that phenomena that can be directly observed (dissolving, burning) are commonly conceptualised at two very distinct levels (Johnstone, 1982): by a formal description and categorisation at the macroscopic level and through explanation of observed behaviour based upon theoretical models of the structure of matter at a submicroscopic scale (Taber, 2013).

Early in secondary education, students are normally presented with a basic version of kinetic theory, which models matter as composed of myriad particles that are much like tiny billiard balls that engage in perfectly elastic collisions. Arguably this is a model deriving from physics, and it can explain states of matter and phase changes—at least when the notion of the particles having some kind of 'holding power' for each other is included in the model (Johnson, 2012). Although there is a lot that *can* be explained with this model, the notion of matter comprising of particles that bounce off each other without being changed by the interactions does *not* provide a strong basis for explaining chemical change.

In the ASCEND activities, the delegates were provided with two paragraphs describing different models of the structure of matter. One model was the basic kinetic theory model of hard spheres that undergo perfectly elastic collisions. The other model referred specifically to molecules with electron clouds that could overlap and interactions between the charges in different molecules. The delegates were also given a list of phenomena (e.g. an ice cube melting, starch being converted to glucose when mixed with saliva), and their task was to decide in their small groups whether each of the phenomena could be explained by one or other, or both, of the two different models.

The underpinning thinking here is that in upper secondary science, learners are presented with models of the structure of matter suitable for thinking about chemical processes which are inconsistent with the basic particle model they have previously learnt to explain the nature of solids, liquid and gases. Engaging with this apparent contradiction would seem to require quite mature thinking in terms of Perry's scheme of development. Students who are concerned with developing a coherent understanding of the nature of matter have to either challenge the teaching they experience or engage with the nature of models in science and science learning.

The second activity was similar in structure—two inconsistent models at the submicroscopic level and a list of phenomena to be explained—but concerning two different models of bonding in sodium chloride. One of these models was based in curriculum science, that is, a model based upon the bonding as an electrical attraction between charged ions. The other model presented was based upon a common alternative conceptual framework of ionic bonding elicited from learners, which sees sodium chloride as forming molecule-like entities due to a fictitious electron transfer from a sodium atom to a chlorine atom that somehow comprises the bond (Taber, 1994; Taber, Tsaparlis, & Nakiboğlu, 2012). The phenomena to be explained included two simple practical activities, observing decrepitation on heating NaCl crystals and observing precipitation of silver chloride when silver nitrate solution is added to sodium chloride solution, as well as a range of statements about properties of sodium chloride.

From a curriculum science perspective, this task might seem easier than the first, as one model is clearly superior in explaining most of the phenomena: however, it is known that many students find the 'molecular' model of NaCl very convincing. From our observations of the students undertaking the two tasks, these learners experienced the activity as genuinely challenging and certainly did not find either task to be obvious or trivial.

3.3 Student Responses to ASCEND

At the end of the programme of seven after-school sessions, the delegates were asked to offer feedback on their experience of being involved in ASCEND (Taber & Riga, 2006). One of the questions asked was: *What did you enjoy most about being involved in this project?* As this was an open-ended question, students were free to suggest whatever they wished, and there was a range of responses. However, one feature suggested by a number of students was that they had most enjoyed the group work ('working in groups to work out things'), whilst a number of others noted the subject matter being distinct from their school science lessons. However by far the most popular type of answer was classified as being about 'exploring ideas' (see Fig. 3).

So students highlighted:

- Exploring new ideas and a new way of thinking. We were not just told facts but asked to think and question our knowledge.
- Thinking about more complex ideas in the theory of science.
- Thinking about more complex things that I haven't thought about before.
- Getting the opportunity to tackle interesting and stimulating problems.
- Being involved in interesting discussions.
- Discussing and listening to ideas and theories.
- In-depth discussions, understanding complicated things.
- I got to come up with theories and present my point of view.
- It stimulated me to think about science from different angles. It made me think about simple things on a deeper level than I've been taught. It made me realise how little of the simple things I remember.

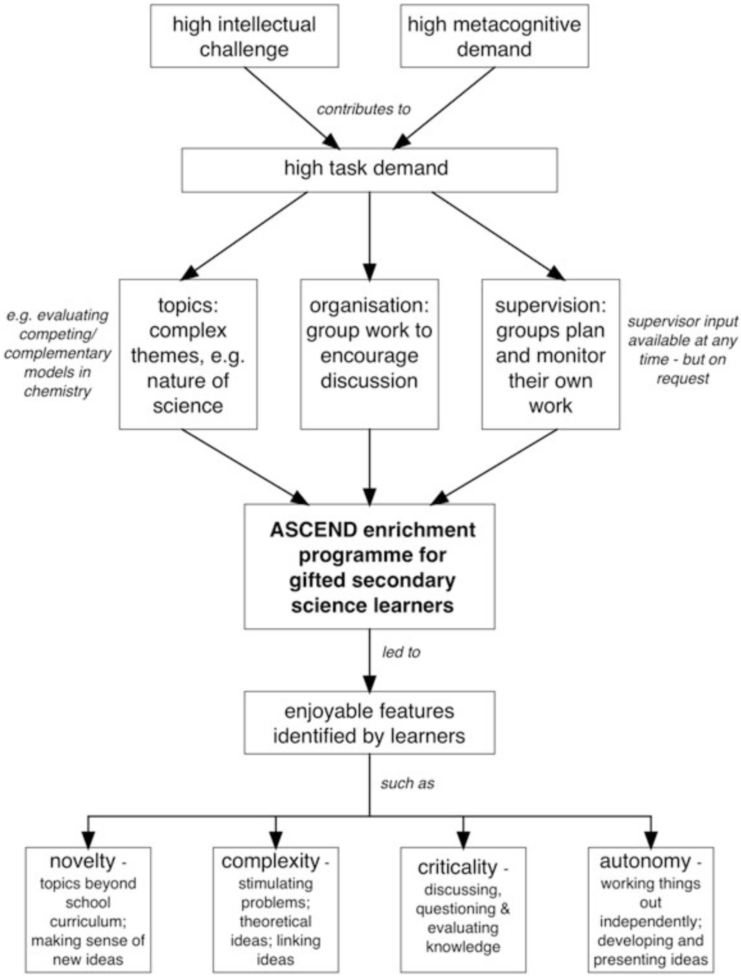

Fig. 3 The design of the ASCEND project offered intellectual demands matched to gifted learners, which allowed them to enjoy a higher level of intellectual engagement

- Chance to think independently.
- Discussing my ideas and working things out.
- Discussing different ideas that we had and finding things that made *other* things make sense.

It should not be surprising that being asked to engage in in-depth exploration of complex questions that facilitates 'understanding complicated things' should be linked with enjoyment, for as Trout suggests, 'there is a special kind of intellectual satisfaction—an affective component—that occasions the acceptance of an explanation, a sense that we have achieved understanding of the phenomena' (Trout, 2002, p. 213).

Another question asked learners what they had found challenging about the sessions, and responses included 'reasoning my ideas, not just taking what I had been taught on face value'; 'thinking about the connections between various things'; 'thinking for myself, thinking beyond the box'; 'sometimes we have to decide something that is not very clear' and 'not being given the answers immediately when asked'. When asked what they felt made the ASCEND activities distinct from school science, the delegates gave a range of suggestions but referred to the work being 'much more intense and in more detail' and involving 'more complex discussions'.

Delegates referred to how the activities had made them 'much more independent' as 'they made us do the work rather than being told it'. One student noted that 'this is more like self-learning whilst in school most stuff is taught by teachers', and another responded that 'we were given a lot more space to think for ourselves and allowed to develop ideas further' compared with school science. One of the delegates suggested that unlike in school the ASCEND sessions had not involved work being 'dumbed down for others'.

3.4 Implications to Be Drawn from the ASCEND Project

ASCEND was one project carried out in one educational context, and care should be taken in generalising from one example. Two major limitations of the programme were that the schools selected those they considered gifted in science based on their own criteria and the ability range of delegates was broad (our perceptions was the cohort included some highly able learners but also some capable and enthusiastic students who probably would not have been considered gifted in most national contexts) and that most activities had not been piloted to any great extent in advance, so there had been no chance to fine-tune the level of demand of the activities to the need of the target group (gifted 14–15-year-olds learning science in the English curriculum context).

Despite some caveats, ASCEND demonstrated that it was possible to design science activities based around 'nature of science' themes that gave students a feel for science as a challenging intellectual activity and that engaged learners over extended periods of time (e.g. an hour for a complex activity, cf. school lessons usually divided into short structured tasks), working with limited input from teachers and requiring learners to take some responsibility for monitoring and evaluating their own progress on tasks.

In the case of the chemistry-specific activity, one of the potentially challenging and demotivating aspects of learning chemistry—being taught apparently inconsistent accounts of chemical concepts—was addressed directly by being explicit about the nature and role of models being used in chemistry and asking learners to (1) consider apparently contrary accounts as models that have particular ranges of application (as they are understood in chemistry itself) and (2) evaluate their utility in that context.

Our evaluation based upon the feedback of the learners who attended ASCEND was that the activities were experienced as quite different to school fare and that accordingly the work was challenging, seen as complex, lacking obvious ‘right’ answers and requiring extended engagement with ideas. However, these features of the programme that provided a high level of intellectual challenge also seem linked to the features that the students told us they most enjoyed, being given complex issues to consider and allowed to develop their ideas and arguments without the frequent interruptions and input from teachers that characterised their experience of school science lessons.

That is certainly not to suggest that the science teachers who worked with these learners in school were misjudging the amount of input needed by *many* of the students in their classes: quite likely other students in the same classes were better suited by work which was more tightly structured and sequenced into more readily achievable subtasks and benefitted from regular teacher input in the form of reminders, hints, checking on progress and on thinking to date (cf. Chapter “Meeting Educational Objectives in the Affective and Cognitive Domains: Personal and Social Constructivist Perspectives on Enjoyment, Motivation and Learning Chemistry”). The difficulty in class teaching is offering the level of structure and support—the scaffolding that allows successful completion of task that is needed by some students—without trivialising the demands of activities for the more gifted students. The challenge for the teacher is to differentiate the level of support so that the challenge of activities matches the needs of different students in the same class.

However, in principle, differentiation by support is certainly one strategy that teachers can use: where what is essentially the same task is given to all of a class, but there are different expectations in terms of the amount of support provided to different groups of learners within the class. In principle this could be combined with the point made earlier about the potential of offering choices for motivating learners. Students could be offered versions of tasks with different levels of support built in, although that strategy does depend upon student having already developed sufficient metacognitive skills to understand the purpose of the strategy and to evaluate their own learning well enough to make effective choices.

The more gifted learners can only experience ‘flow’ in their learning when they are given the opportunity to engage in sufficiently demanding activities to experience a challenge, knowing that they have been given genuine responsibility for planning and organising their learning, and sufficient time to explore the complexity of the task and make real progress before they are asked to account for their work. The highly scaffolded tasks and constant checking and feedback by teachers that is necessary for some learners can actually undermine the deep engagement of the most able in a class. Yet, as was illustrated in ASCEND, when gifted students are suitably challenged and also given genuine scope to respond to that challenge, they not only enthusiastically engage in exploring concepts and theories, but they also report enjoying the experience.

Acknowledgement The ASCEND project was supported by the Gatsby Science Enhancement Programme, who funded the after-school enrichment programme and published an account of the project with the full set of teaching materials (Taber, 2007b). The programme was run as a partnership between the University of Cambridge Faculty of Education, Chesterton Community School, St. Bede's Inter-Church School, Netherhall School and Sixth Form College and Parkside Community College. Fran Riga acted as the research assistant to the project and helped collect and collate the feedback from delegates.

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It's the Situation That Matters: Affective Involvement in Context-Oriented Learning Tasks

Sabine Fechner, Helena Van Vorst, Eva Kölbach, and Elke Sumfleth

Abstract This chapter focuses on the evaluation of affective variables in context-based learning (cbl) environments. Although the majority of studies in the field have shown positive effects on attitude, the need to investigate specific elements of cbl tasks has become evident. On the basis of prior research designs and instruments, it is argued that attitude has to be perceived as a multifaceted construct. Different research designs and attitude instruments are discussed and related to the theoretical background of motivation and interest. In the second part of the chapter, three studies are presented that address the need to differentiate between different contexts, content elements, and attitude measurements. Therefore, the general statement that cbl courses have a positive effect on student attitude is maintained, however, enriched by a more differentiated and substantiated perspective that may shed light on how to select an adequate context within a specific content-related area.

Keyword Context-oriented learning • Context characteristics • Situational interest

1 Introduction

Context-oriented learning has been introduced to address one major problem of chemistry classrooms: students' indifference and disinterest in learning chemistry content. The early so-called STS approaches in the 1980s placed emphasis on the relation of science, technology, and society in order to make chemistry relevant to students by illustrating its importance in issues connected to the learners' life-world

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(Aikenhead, 1994). Especially issues in technology were highlighted by approaches like the Dutch *Project Leerpakket Ontwikkeling Natuurkunde* (PLON; eng: Physics Curriculum Development Project) (Kortland, 2005). In the following decades, context-based programs, focusing more generally on the life-world of students, sprang up like mushrooms (Nentwig & Waddington, 2005): programs like "Chemistry in the Community" (ChemCom) were established in the USA (Sutman & Bruce, 1992); the "Salters Family" of cbl courses, which included courses focused on chemistry, were developed in the UK (Campbell et al., 1994); and, eventually, "Chemie im Kontext" (ChiK) was introduced in Germany (e.g., Nentwig, Demuth, Parchmann, Gräsel, & Ralle, 2007). In these programs, a cbl environment can generally be regarded as a student task in the chemistry classroom that directly relates content knowledge to a nonscience-related situation within the students' experience. For example, students might learn about the chemical concept of concentration and ionic bonding by being involved in a situation where the water quality of a swimming lake is investigated (Bulte, Westbroek, De Jong, & Pilot, 2006). Although implemented in different ways and on the basis of different goals, all programs unify one all-embracing assertion: students should feel comfortable and positive towards chemistry when they learn chemistry in a context-based environment.

Although research has confirmed this assertion in general (cf. Bennett, Lubben, & Hogarth, 2007), it is assumed that the effects of cbl environments in chemistry education rely on the specific setting in which they are enacted (Gilbert, 2006). The selection of context situations for the task as well as the chosen student activity might have a different influence on the enhancement of positive affect in students and might thus provide a different potential for fruitful learning processes in the domain. Therefore, this chapter aims at taking a differentiated look at cbl tasks and their effect on certain facets of affect. The context situation students are confronted with in the learning task and the respective underlying content knowledge are considered as crucial factors in the enhancement of affect and are discussed with regard to the theoretical construct of situational interest as a content-related facet of affect.

2 The Affective Dimensions of Context-Oriented Learning

Taking a closer look at the aspects of an activity that may have the power to enhance positive student affect, a variety of facets have to be considered: it might be the underlying content of the task (e.g., acids and bases in chemistry), the embeddedness of the topic (e.g., task situation), the social mode (e.g., group activity), the openness of the task (e.g., inquiry-based), or the fit of the task difficulty to student competence (e.g., adaptation to student needs). Thus, it is necessary to describe the concrete situation in which learning takes place. According to Finkelstein (2005), three levels of context have to be clearly differentiated in science education in order to avoid confusion of terms: the *task*

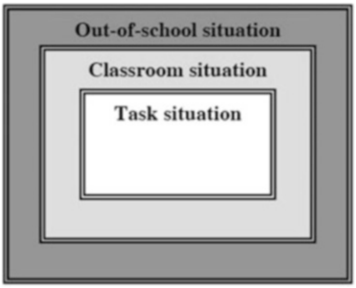

Fig. 1 Levels of context in science education [adapted from Finkelstein (2005)]

situation, the *classroom situation*, and the *out-of-school situation* (Fig. 1). While the task situation refers to the specific content-related situation a task is embedded in, like the storyline of a problem introduced to students, the classroom and out-of-school situations are rather social and/or cultural in nature. The classroom situation describes where and how the task takes place (e.g., group work in the lab), whereas the out-of-school component adds the cultural aspects that influence learning (cultural attitude towards being engaged in the task).

Context-based learning may take place on all levels and might thus be examined on each level. In this chapter, "context" is not regarded as the surrounding social and structural dispositions but as the situation presented in the learning task that can directly be connected to chemistry content. While learning on the other levels is dependent on general educational choices, the situation in the learning task does clearly relate to chemistry content knowledge. Thus, not only the task situation (context) might have an effect on the affective domain but also the underlying chemistry content knowledge and the interaction of the two.

The affective domain in chemistry education is basically concerned with factors that positively influence students' engagement in a learning activity. For example, when the content and context of a task are considered, the theoretical construct of interest comes into play. "Interest is conceptualized as an affective state that represents students' subjective experience of learning; the state that arises from either situational triggers or a well-developed individual interest" (Ainley, 2006, p. 391). As well-developed individual interest in chemistry content is generally low (Osborne, Simon, & Collins, 2003), situational triggers have to be considered to make chemistry learning more attractive to students. Here, a task situation within the students' own experience (e.g., swimming lake) can be used as a trigger of situational interest.

Interest theories like the person-object theory (Krapp, Hidi, & Renninger, 1992) define situational interest as strictly object-dependent or as being conceptualized in direct relation to an object of learning. Schiefele (1991) further defines interest "as a content-specific intrinsic motivational orientation" (p. 303) and discusses two valences of situational interest that further describe the construct: emotion- and value-related valences. Emotion-related valences refer to the positive experiential state during a content-related activity, while value-related valences embrace the person's attribution of personal significance to the content of the activity.

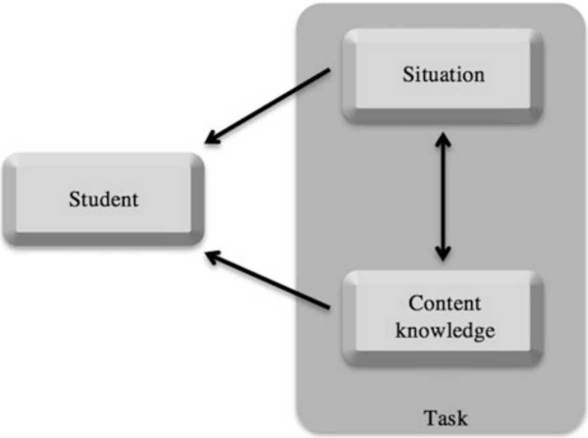

Fig. 2 Structure of a context-oriented task in relation to a student engaged in a learning activity; cf. Van Vorst et al. (in press)

Taking the relation between a person and an object of learning into consideration not only means assigning an affective but also a cognitive component to the interest construct because the object of interest might be related to a specific content-related task in the classroom.

In order to satisfy the assumptions of the person-object relation of interest, we perceive the cbl task as a situation and its interrelation to chemistry content (see Fig. 2). The situation can be defined as a non-content-related trigger to catch student interest. It is provided in a learning task in the form of a written or oral story to which content knowledge can be related. Situation and content knowledge constitute the whole task and are considered the object of learning that affects the student.

3 Empirical Evidence on Affective Dimensions in cbl

Investigating the affective response of students to context-based instruction has confirmed that context-based learning triggers positive affect. Considering the studies included in the two major reviews on cbl in science education (Bennett et al., 2007) and chemistry education (Ültay & Calik, 2012), students learning chemistry content within contexts of their life-world profit with regard to the affective dimension of learning. Although there is consent among science education researchers about this positive effect, there is a lack of empirical evidence on the differentiated aspects in cbl that generate it. Therefore, we do not intend to argue whether cbl is capable of raising positive affect but will examine the determinants that lead to its emergence.

Taking a closer look at the studies included in the reviews mentioned above, it becomes obvious that general conclusions should only be drawn on cautious grounds. Although the phrase "attitude towards chemistry" seems to be the most commonly used descriptive phrase in order to describe student affect, authors also switch between nouns like "enthusiasm" and adjectives like "attractive" and "interesting" without defining or theoretically substantiating their perception of the underlying affective construct.

Because of this, our goal is to focus on different characteristics of a cbl environment and student prerequisites that have the potential to influence affective variables in a positive way. We merge empirical evidence from three studies that have been conducted in our research group (Fechner, 2009; Kölbach 2011; Van Vorst 2013). This offers the opportunity to compare data that were measured with the same instruments. We imply that higher affect can be seen as one basis to make fruitful learning in chemistry possible. However, we focus on different aspects of the task situation and their respective influences on affective variables. This will make it possible to provide curriculum developers and teachers with guidelines to select contexts for the chemistry education classroom.

Scrutinizing the empirical evidence of previous studies (Bennett et al., 2007; Ültay & Calik, 2012), the learning environment is rarely described in enough detail to elicit the specific context used in the learning task and its underlying content knowledge. Most studies evaluate whole context-based courses (e.g., Barber, 2000; Smith & Matthews, 2000; Yager & Weld, 1999), so that it is not possible to relate results to the respective task situation nor the content knowledge addressed in the course.

Attitude measurements generally also focus on student motivation to enroll in the course, interest in school science, or perceived relevance of school science. Measurements are mostly based on Likert-like scales (Barber, 2000; Demircioğlu, Demircioğlu, & Çalik, 2009; Overton & Potter, 2011; Schwartz, 2006) and open-ended questions in questionnaires (Barber, 2000) or interviews (Ramsden, 1997). Few studies validated their results via triangulation (Barber, 2000) and none via construct validity (e.g., factor analysis).

4 Situations May Differ

4.1 Situations as Contexts

Asking science educators and practitioners what an ideal "context" should be like, terms like "relevant," "authentic," or "realistic" are mentioned. Likewise, the literature on context-based conceptions also reproduces this vague image by stating that cbl tasks are "real-world societal problems" (Schwartz, 2006) or "start with aspects of the students' lives, which they have experienced either personally or via the media" (Bennett & Lubben, 2006).

However, large-scale empirical studies like the ROSE (Relevance of Science Education) study (Jenkins & Pell, 2006) have shown that student interest in different real-life topics is highly dependent on learner prerequisites and covers a wide range of learner responses.

Only if detailed characteristics of a context are worked out and substantiated it becomes possible to design contexts with a high potential to generate content-related situational interest.

Because of this need to further investigate the composition and effect of a context, Van Vorst (2013) has worked out specific characteristics of a context on the basis of a literature review. Her theoretical account focuses on the characteristics of a context as being (1) authentic, (2) related to students' everyday life, (3) unique, (4) topical, or (5) relevant and how they affect students in a cbl environment.

According to Van Vorst (2013), AUTHENTICITY is referred to often in the literature. It can be described by the format of display (e.g., newspaper article) and its complexity (degree of interconnectivity). If a newspaper article is written to meet the educational needs of elementary students, the complexity might not fit the usual format and may lead to lower credibility on the students' side. Generally speaking, the student perceives the specific task situation as more or less credible based on their perception of its authenticity. Another characteristic of cbl which is often referred to in the literature is that learning environments should relate to the students' EVERYDAY LIFE. This characteristic can be described by means of the immediacy and frequency of a situation that is encountered by the student, e.g., as a task that asks students to work on a problem within a common household (e.g., properties of detergents). On the contrary, UNIQUESS can be described as a characteristic of a task situation that is not encountered within the students' immediate life-world. Phenomena in a foreign country or alien life would be examples of this group.

If the context relates to an event that is repeatedly presented in the media, it will have high PUBLICITY within the sociocultural environment and may thus influence the perception of the learner. It can refer to either everyday or unique situations and describes how well known the situation is to the student in the sociocultural environment.

In order to structure the characteristics, Van Vorst and colleagues (in press) provide a framework as a theoretical overview of the relationships between the characteristics of a cbl task situation and learner variables (see Fig. 3). The characteristics of a context (see middle column) are dependent on the descriptive aspects in the actual learning task (see situation, right column) and its effect on the student (see student, left column). Thus, AUTHENTICITY is determined by the task situation (*What kind of a format does it have? How complex is its contents?*) *and* the credibility it generates to a specific student. The same task situation might thus be perceived in a different way by students of a different age, expertise, or background.

The RELEVANCE of a cbl environment to a particular student might be dependent on all the characteristics and should not be considered without a look at a definition of the term. However, Stuckey, Hofstein, Mamlok-Naaman, and Eilks (2013) state that relevance lacks a clear definition within the science education community because it needs further elaboration on what is relevant to whom. Within cbl environments the situation is considered to make content knowledge relevant to students by evoking interest. However—as the authors state—"some aspects of

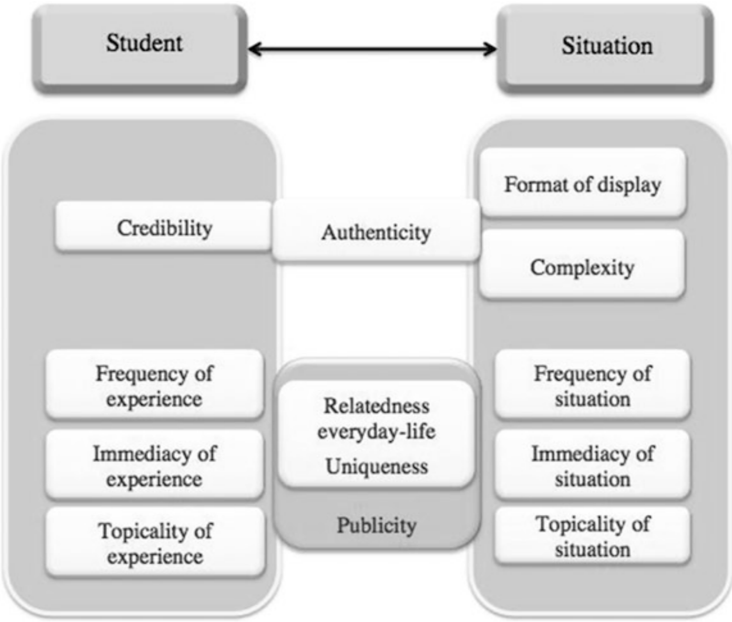

Fig. 3 Framework to describe characteristics of a cbl task situation (*right*) in dependency to learner variables (*left*); cf. Van Vorst et al. (in press)

science education can be relevant without the students being interested in them (and vice versa)" (Stuckey et al., 2013, p. 9). Within chemistry education, for example, even the very uninteresting periodic table might become highly relevant to a student who wants to pursue a scientific career in the field of chemistry.

Furthermore, it cannot be neglected that a context might also have societal relevance without evoking a feeling of relevance in the student. Thus, it can be stated that societal relevance can rather be determined by the factors that compose the actual situation (see Fig. 3, right column) while student relevance is determined by the individual perception of the student (see Fig. 3, left column).

The characteristics of a context-oriented learning task have been described to offer an approach to categorize, structure, and evaluate learning material on the basis of a reference system. As will be discussed below, it might be expanded by further characteristics and should be regarded as a working framework.

4.2 Situations and Content Knowledge

The literature has often highlighted inconsistent empirical evidence with regard to the cognitive effects of context-based learning (Bennett & Holman, 2002). Even if a cbl environment catches interest by means of a context, it does not necessarily lead to higher learning gains in students. With this respect, the literature on cbl introduces the so-called need-to-know (Pilot & Bulte, 2006) as a prerequisite of cbl environments. Situations are only regarded as fruitful for learning, if they evoke a need-to-know content knowledge in the learner. Mostly, the situation is presented as an open and problem-oriented learning task that offers the learner the possibility to experience their own need to get involved in finding out about the content knowledge hidden behind the situation.

Researching such learning tasks, however, has to differentiate between affective states that are content-specific or activity-related because the cognitive character might have higher power to predict learning outcomes. Furthermore, even if both constructs have effects on learning, they might be manipulated by different elements in the learning environment.

Whether affective states might foster or hinder learning has been investigated in educational research on learning from texts (Schraw, Flowerday, & Lehman, 2001; Schraw & Lehman, 2001). Evidence from this field can be used to develop fruitful guidelines to design cbl environments in the chemistry classroom that have a positive effect on learning outcomes. Specific text characteristics, like the relevance of text information, are found to have a significant influence on situational interest and text comprehension. However, this assumption is put into perspective by research on “seductive details” (Wade & Adams, 1990; Wade, Schraw, Buxton, & Hayes, 1993). In this research, motivation is raised by elements without any cognitive relevance. Thus, a context might raise interest in students by giving a rich and colorful account of a situation without providing enough opportunities to need-to-know content knowledge. In this case, the cbl environment will potentially catch student interest but would fail to provide a fruitful basis for learning chemical concepts.

On the basis of the presented research evidence, the implication for cbl tasks would be to examine the situation of the task according to both the need-to-know which is evoked in students and the possible seductive details in the situation that might distract students from feeling this particular need-to-know. For example, if sports are chosen as a situation in which to discuss chemistry knowledge, students may feel a higher need to discuss the performance of their favorite team in the national football league rather than focusing on the underlying content knowledge. Practitioners have to be aware of this and structure their task accordingly.

5 Merging Results of Three Studies on Interest in cbl Tasks

5.1 Research Question and Data Sources

As research evidence on situational interest in cbl learning environments is rare, our group conducted a series of studies dedicated to reveal the relationship between particular characteristics of context, content knowledge, and their impact on situational interest as well as knowledge gains. In this chapter, we intend to extract and summarize the evidence on different characteristics of a cbl task and their influence on affective variables. Thus, the overarching research question for the following section would be:

Which characteristics of a cbl task influence the affective domain?

5.2 Methodology

The three studies providing evidence for the influence of cbl on the affective domain and their design are summarized in Table 1.

Table 1 Overview of studies discussed in the chapter

Study	Learning environment	Comparison environment	Measured variables	Validity of test instrument
Fechner (2009)	*Situations*: Categorizing household solutions; cooking red or blue cabbage; making cleaning detergents less harmful; soda maker; treating acid football soil *Content knowledge*: acid-base chemistry *Activity*: Inquiry-based hands-on cbl tasks	Control group	Topic-related situational interest Activity-related intrinsic motivation	Construct validity by factor analysis
Kölbach (2011)	*Situation*: Swimming lake *Content knowledge*: water, salts *Activity*: Worked examples	Control group	Topic-related situational interest	Construct validity by factor analysis
Van Vorst (2013)	*Situations*: Contexts that were rated as everyday or unique and topical or non-topical (see p. 6)	Only situations are compared according to their characteristics	Topic-related situational interest (value) Topic-related situational interest (emotion) Topic-related situational interest in learning chemistry (value) Topic-related situational interest in learning chemistry (emotion)	Construct validity by factor analysis

5.3 Design

Fechner (2009) compared five different context situations (e.g., harmfulness of detergents) all related to the same chemical content knowledge (acids and bases) within an inquiry-based learning activity. Students could perform hands-on experiments starting from a problem situation that was embedded into an everyday context. Situational interest in the topic and intrinsic motivation in the activity of task was measured after each session and compared to a group that performed the same tasks embedded within a laboratory situation.

Kölbach's (2011) study compared different chemistry content areas (water as a substance and properties of salts) within the same context situation (swimming lake). Learning from a scaffolded problem-oriented text, students individually learned the content. Situational interest in the topic of task was measured after each session and compared to a group that performed the same tasks embedded within a laboratory situation.

Van Vorst (2013) concentrated on different characteristics of a context situation (see above) and developed introductory texts that can be seen as the starting point of a cbl learning task. Each text could be assigned one combination of the characteristics (high/low TOPICALITY and EVERYDAY/UNIQUE). Situational interest in the introductory text to a potential cbl task was measured for the different texts on the scales listed in Table 2.

5.4 Instruments

Data on student affective responses towards context-based chemistry should directly be collected by asking students for their responses by either Likert-type questionnaires or interviews rather than asking for potentially biased teacher perceptions (Ramsden, 1994). According to Bennett et al. (2007), student responses should additionally be compared to earlier experiences in a traditional chemistry class or a control group in order to provide a point of reference. The research instrument should be discussed with regard to its construct validity by either triangulating data from questionnaire and interview or performing factor analysis on quantitative data.

The reported studies used selected scales from the same test instruments on situational interest (see Table 2). Items were mainly retrieved from a study on out-of-school learning environments (Engeln, 2004). All studies used two scales with items on a four-point Likert scale asking for student situational interest in the task (*After I had read the task, I was very interested in the topic*) and the activity (*Doing the activity was great fun*). Situational interest in the task was additionally subdivided into items related to a value- or emotion-oriented valence (see Table 2). Factor analysis was performed in order to ensure construct validity.

Table 2 Scales used to measure different situational interests in the studies

Scale description	Item example
Topic-related situational interest (value)	I think today's topic is of personal importance to me
Topic-related situational interest (emotion)	After I had read the task, I was very interested in the topic
Topic-related situational interest in learning chemistry (value)	To learn the chemistry behind today's topic is of personal importance to me
Topic-related situational interest in learning chemistry (emotion)	After I had read the task, I was very interested in the chemistry behind the topic
Activity-related intrinsic motivation	Doing the activity was great fun During the activity, I did not think about anything else

Although the literature on emotion- vs. value-related valences of situational interest predicts that the two can hardly be extracted empirically (Rheinberg, 2004), this assumption was only confirmed in two of our studies (Fechner, 2009; Kölbach 2011). However, different scales could be extracted in the two studies although they used the same items on situational interest: while Fechner could extract an activity-related vs. a topic-related scale, this was not possible in Kölbach's study.

In the third study (Van Vorst, 2013), factor analysis extracted emotion- and value-related scales (see Table 2). Students had to rate their interest in learning chemistry knowledge starting from a presented context. As this situation was rated without an explicit reference to content knowledge, items asked for interest in the introductory context as well as if it was used in the chemistry classroom. Because situations did not include an explicit learning activity, activity-related interest scales could be excluded. A reason for the extraction of both valences can be seen in the procedure which combined a large sample with a variety of situations to be rated with regard to different characteristics.

The results of the studies are presented in close connection to each other in order to make tendencies evident that may form the basis for general educational rules, further research challenges, or classroom practice.

5.5 *Results: Different Characteristics—Variations in Interest*

In 2007, the first study was designed and evaluated (Fechner, 2009). Although the aim of the study was primarily to further the evidence on context-based vs. traditional learning in a controlled setting rather than focusing on selected contexts, it was possible to detect differences in effects between the contexts. The learning environment in this study consisted of five consecutive inquiry tasks with different problem-oriented contexts in the area of acid-and-base chemistry. As the learning environment was developed in an open and student-oriented way, the motivational variables with respect to the activity were supposed to be high in the

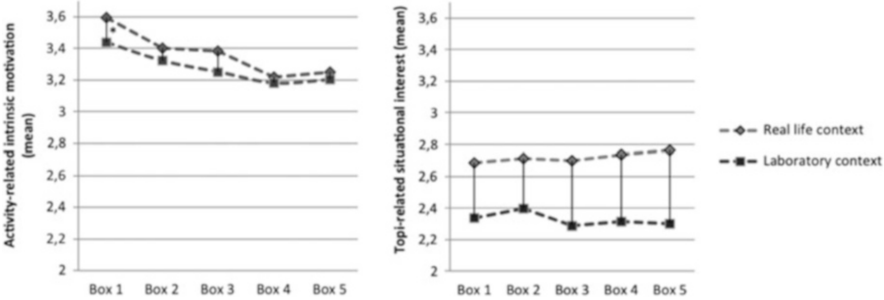

Fig. 4 Measures of activity-related intrinsic motivation and topic-related situational interest (Fechner, 2009)

experimental and control group. On the ground of the presented theories, only differences in content-related situational interest were expected. As can be seen in Fig. 4, activity-related intrinsic motivation was high in all groups pointing at the fact that the character of the learning environment and possible novelty effects might have induced the motivational state. The differences between the two context groups were not statistically significant.

Taking a look at the topic-related situational interest levels measured immediately after each learning task, differences between the groups become obvious: effects are significant at all testing points. Moreover, a tendency can be estimated from the second inquiry task onward, showing that situational interest is kept up in real-life context tasks, while students in tasks with a laboratory context lose interest.

Because effect sizes were quite different between the different tasks, we concluded that certain context characteristics might predict certain degrees of situational interest. In consequence, Van Vorst (2013) developed context situations on the basis of the different characteristics shown in Fig. 5 that have been introduced above. The two main research questions were concerned with (1) interest differences and (2) whether the characteristics could predict interest differences to a higher degree than topic-related areas like hobbies. In order to investigate the research questions, Van Vorst developed situations which could unambiguously be assigned to one of the characteristics shown in Fig. 5. In each cell, two situations were developed referring to one of the three topic-related areas nature, hobbies or traffic. In each cell, one example is given to illustrate the particular characteristic.

The most striking result was that students preferred unique situations unrelated to their everyday life. With regard to the emotional valence of topic-related situational interest, students perceived higher interest for unique rather than everyday situations independent of their TOPICALITY (Fig. 6). They showed more interest in a forest fire rather than a regular mosquito bite. With regard to this measure, the characteristics proved to result in higher differences than the topic areas.

Similar results could be found for the value-related measures. However, unique situations were only rated as interesting on the value-related scale if they were highly topical. Concerning the topic areas, differences could merely be found with

	Topicality – *Yes*	*Topicality* – *No*
Relatedness to everyday life	Nature: Mosquito bite Hobby: Open air bath Traffic: Holiday flight	Nature: Scent of roses Hobby: Page of book Traffic: Bicycle tyre
Uniqueness	Nature: Forest fire Hobby: Women's championship Traffic: Air con of speed train (failure)	Nature: Rare beetle Hobby: Rare music instrument Traffic: Airbus A380

Fig. 5 Situations included in the study with their context characteristics; examples are provided within the cells

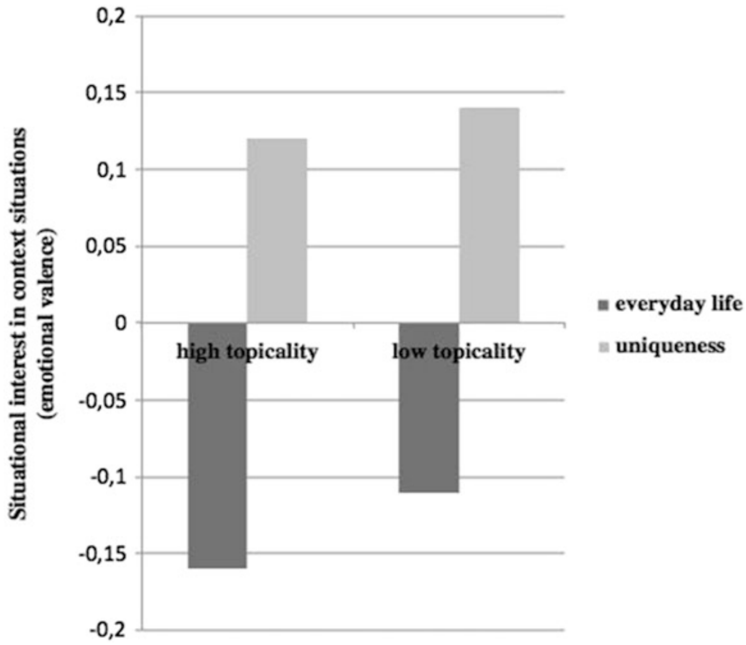

Fig. 6 Results of situational interest in context situations (emotional valence)

regard to the area of traffic. Here, the topicality scale showed differences: high topicality was judged most interesting if the topic was traffic-related irrespective of its uniqueness vs. relatedness to everyday life. Results may imply to include the characteristic of "risk" into the assignment of characteristics to situations. Literature on gender differences in interest has shown significant results in this area (Jenkins & Pell, 2006) with boys being more attracted to explosives and dangerous chemicals. In our study, similar results can be found on the emotional scale within the area of traffic where male students show significantly higher interest.

Although students knew that the situation was supposed to be subject of their chemistry class, they rated it less positively if the items explicitly asked them for their interest if chemistry content knowledge was to be acquired by means of these situations.

This result can be seen as a hint that interest in a task is both influenced by the situation provided to students, general individual interest with regard to the underlying chemistry content knowledge, and interest in the activity of learning content knowledge. Thinking the opposite way around, content knowledge might be judged more interesting if perceived through the lens of an attractive situation. Hence, the potential to influence learning in a positive way by incorporating interesting situations into a learning task should be high if the underlying content knowledge is regarded as unattractive.

5.6 Results: Considerations of Content Knowledge and Interest

If studies on interest in chemistry are considered, students generally show low interest in the subject and their chemistry classes (Osborne et al., 2003). On the other hand, the low performance of students in chemistry or science in comparative large-scale assessments makes it seem likely that low performance might be caused by low interest levels. Students do not seem to reach an adequate motivational state to be open to learning chemical concepts. This makes a more detailed look not only at different situations but also at different aspects of content knowledge (e.g., properties of salts) necessary. As mentioned before, the need to introduce cbl becomes particularly apparent if the underlying content knowledge is not interesting at all.

In our second study, this interaction between interest in situation-related vs. -content-related elements becomes evident. As can be seen in Fig. 7, even students in the laboratory group show relatively high interest levels if they learn within the content area of "water as a substance" rather than "properties of salts."

While both groups show similar situational interest levels within the situation of the swimming lake, students prefer the contents *water* rather than *salts* in the laboratory environment. This may be explained by the fact that water could also be assigned a high degree of the characteristic of RELATEDNESS OF EVERYDAY LIFE. Although being confronted with the liquid in a laboratory environment, students seem to be able to transfer its significance from their everyday life. Although salts also play a significant role in our everyday life, students estimate the content-related relevance of water and its property high in both groups whereas salts and their solubility is only judged relevant in the real-life context group (Kölbach & Sumfleth, 2013).

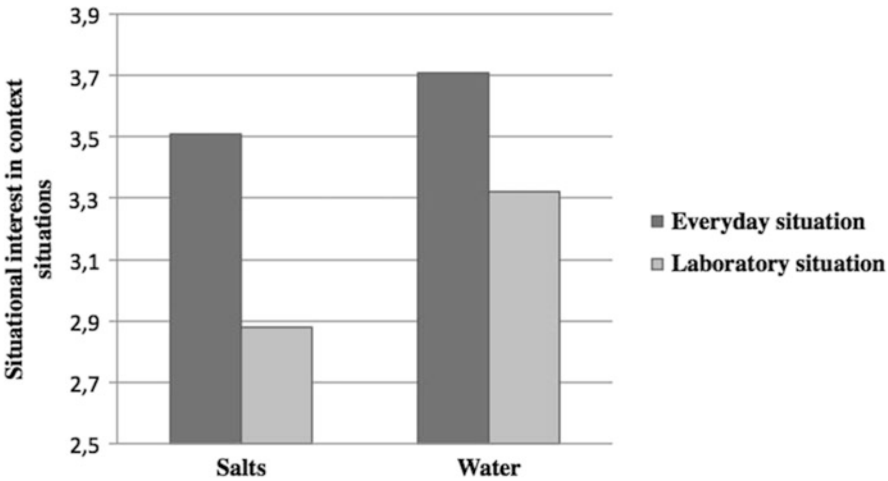

Fig. 7 Measures of topic-related situational interest in one context (swimming lake) with different situations and underlying content knowledge (Kölbach 2011)

The results are in line with results from earlier studies. In a comparison study, the intervention study of Fechner (2009) was replicated in biology education (Haugwitz, 2009). As biology is more related to the students' everyday lives, the subject ranges high in interest rankings (Merzyn, 2008). Based on the assumption that cbl is only effective if the context situation and the underlying content knowledge have a high discrepancy with regard to their interestingness, cbl should have minor effects in biology. Results confirm this assumption although some contexts also show effects in biology (e.g., playing football as a context situation). Applying the results of Van Vorst (2013) to this comparison study, learning biology should be even more interesting if unique and risky phenomena are included into the learning task as situations to evoke a need-to-know.

6 Discussion of Findings

Large-scale studies like the Relevance of Science Education (ROSE) study have pointed at the need to differentiate between learner prerequisites (e.g., gender, culture) and specific areas of interest. They confirm earlier interest studies providing evidence that science contents and the contexts used to show the application of content knowledge in industry or society should be evaluated separately (cf. IPN study, Gräber, 1992).

However, research evidence up to today has mainly focused on whole courses without the purpose to investigate the effects of single units in more detail. Evidence points at the fact that effects on attitudes and learning are highly dependent on the respective context situation and the underlying content knowledge. Therefore, studies need to address these issues in more detail.

The studies presented in this chapter can be regarded as a step in this direction. By means of experimental designs, different context situations were investigated in relation to different underlying content knowledge and their effect on situational interest measures. By this method, evidence was generated that might become a basis to formulate guidelines to choose contexts as situations in the chemistry classroom. The question of which context to use in relation to what underlying content knowledge was clearly substantiated by the results. Impressively, the study on interest in different situations indicates that students show higher interest levels in unique situations independent of the topicality of the situation. The results of this study suggest that a context should be chosen by means of its characteristics rather than its topic-related area. While there were little interest differences in the comparison of different topic-related areas (nature, e.g., scent of roses, vs. traffic, e.g., bicycle tires), interest levels significantly increased if everyday contexts were substituted by unique contexts within these areas (nature, e.g., a rare beetle instead of scent of roses; traffic, e.g., traveling with the A380 instead of on bicycle tires).

Furthermore, these studies show that contexts are particularly effective if the underlying content knowledge is not at all interesting to students. Acquiring content knowledge within interesting situations makes students feel the need to know more about the chemistry behind the situation. However, although there are dependencies of affective responses and learning, learning gains could not only be predicted by interest. Thus, more research into the factors that make interest an effective predictor of learning should also be pursued.

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Gathering Psychometric Evidence for ASCIv2 to Support Cross-Cultural Attitudinal Studies for College Chemistry Programs

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Abstract Instruments in the affective domain may not be equivalent when the tests are administered to different populations with different cultural backgrounds. To illustrate a general approach, this study was intended to gather psychometric evidence for an instrument of attitude toward chemistry to support cross-cultural attitudinal studies for college chemistry students. The shortened version of Attitude toward the Subject of Chemistry Inventory, ASCIv2, was used at three universities, one in Saudi Arabia, one in Australia, and one in the USA. Based on the results of psychometric analysis of internal consistency reliability and internal structure validity, we found that students from the Saudi Arabian institution responded to item 6, chemistry is challenging or not, differently from those in Australia and the USA. This study signifies the importance of examining utility and student response in context when instrument data is gathered in cross-cultural scenarios, to ensure that responses in the new context still match the trait underlying the instruments. In addition, this study contributes to the use of ASCIv2 regarding the possible variance and profile for attitude scores from multiple countries.

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1 Introduction

1.1 The Need for Attitude

Student attitude toward science is a concern in many countries. For various reasons, such as public and disciplinary concerns about content knowledge and uncertain reliability of measurement for the attitude construct, education accountability policy usually does not consider a student's attitude (The General Assembly of the State of South Carolina, 1998). Similarly, many countries are faced with the pressure to make educational policies focus on content knowledge in order to catch up with top-achieving countries as measured by the international assessments like TIMSS (Martin et al., 2008). This has created a concern that some educators might not perceive the affective domain as important and may pay more attention to students' content knowledge than to their affective growth, which may impact student learning in the long term. Because some also may perceive an attitude score to be subjective and unreliable, effort should be taken to measure and interpret data in a scientifically valid way.

When an attitude instrument is designed for international use, there is a validity concern that the students of various cultural backgrounds may interpret the items differently. The different interpretations of survey items can potentially bias the survey results if users do not take this validity concern into account. In their review, Osborne cited the studies by Taylor et al. (Modood, 1993; Taylor, 1993) and posited that "Asian students have a clear preference to study for degrees in medicine-related studies, engineering or mathematics … Afro-Caribbean students seem to shy away from science preferring to pursue degrees in the social sciences," while "Japanese-Americans were most positively inclined towards scientific careers" (Osborne, Simon, & Collins, 2003). While these sorts of conclusions are intriguing, without examining the instrument function across a number of populations, we cannot be sure whether the observed difference is due to test bias or represents a real difference in the group means (Jiang, Xu, Garcia, & Lewis, 2010; Schroeder, Murphy, & Holme, 2012). Therefore, we need to gather sufficient evidence as to whether or not the instrument functions similarly to measure the same construct across different groups, so we can make a fair comparison using the instrument scores.

In this pilot study an attitude instrument was given to a student sample in Saudi Arabia, and compared to previous results from Australia and the USA (Xu & Lewis, 2011; Xu, Southam, & Lewis, 2012), to examine how an attitude instrument functions in context and how college students' attitude status toward chemistry might differ between each group. Saudi Arabian students are of particular interest in the area of student attitude due to the unique features of the college chemistry programs as compared to other western educational systems such as Australia or the USA. For example, in Saudi Arabia, courses are mostly offered in classes segregated by sex, even in coeducational universities. The major choice is also limited to the programs that these specialist universities can offer, compared to the comprehensive and mixed sex classes in both Australia and the USA.

Research on student attitude has been undertaken in Saudi Arabia with targets as diverse as computers, smoking, eating, and so on (Al-Khaldi & AlJabri, 1998). There is only one study concerning attitude performed in a school chemistry education context from Saudi Arabia (Harty & Alfaleh, 1983). The authors reported very promising results that high school students in a small-group laboratory setting performed better on a chemistry achievement test and exhibited more positive attitudes toward science than those in the traditional setting. Unfortunately, there are no accessible follow-up publications in English on Saudi Arabian students' attitudes in the area of chemistry, though there are some in Arabic (Albaz, 2007; Albusylee, Sadieg, & Abdukader, 1990; Balfagheh, 2001; Fatallah, 2009; Hijazi, 2008). Therefore, this field is in its infancy in Saudi Arabia and needs to be further explored. This study is intended to contribute to understanding how attitude instruments function for college students in a Saudi Arabian context to provide a preliminary attitude comparison with student samples in Australia and the USA. The findings from this study can provide an example to establish evidence for a robust instrument; otherwise it is uncertain whether research findings are just an artifact of the instrumentation. With more knowledge of an instrument's function, the chemistry education community can use the tool with more confidence to support further research investigations, such as how attitude relates to student achievement and the school curriculum.

1.2 Measurement for Attitude

With increased international collaboration in educational reform, there is a need to develop measurement tools with reported psychometric evidence for cross-cultural comparison (Abell, Springer, & Kamata, 2009; van de Vijver & Tanzer, 2004). Valid instrument scores are critical to evaluate the effectiveness of educational programs, to inform instruction, and to help make data-driven educational policies. Psychometric evidence of an instrument's function in the specific context is necessary, to interpret an instrument score, to support claims based on instrument scores, and to meet the current standards for educational and psychological testing (AERA, APA, & NCME, 1999). Accordingly, a conceptual framework for evidence sources was proposed in the area of chemical education (Arjoon, Xu, & Lewis, 2013). Validity refers to "the degree to which evidence and theory support the interpretations of test scores entailed by proposed uses of tests" (AERA et al., 1999). Reliability is necessary for validity and refers to the consistency of a measure and scoring procedures. Reliability evidence can be gathered based on temporal stability, which requires the same respondents to take the test more than once, and internal consistency, which involves examining the degree to which responses to related items correlate with one another. Validity evidence can be collected based on temporal stability, internal consistency, test content, response processes, internal structure, and relations to other variables (Arjoon et al., 2013).

Test content evidence is typically established by asking a panel of domain experts to judge whether the items appropriately sample the domain of interest. Cognitive interviews are often used for gathering response process evidence, providing insight into whether thought processes invoked by test items are those intended by the test developer. Constructed response items can also be useful tools for examining this sort of validity evidence. Respondents need to first understand the nuances of the item and then mentally retrieve relevant information in order to make a decision about how to respond to the item; response process evidence demonstrates respondents' understanding of an item by illuminating their thinking about that item. Relational validity evidence is typically inferred from statistical analysis, such as confirmatory factor analysis and correlation analysis. The internal structure of an instrument, or how the items in the instrument relate to each other, is important because usually an instrument prescribes the intended construct as unidimensional or multidimensional, with specific item sets measuring different aspects of the construct in the latter case. Evidence based on internal structure establishes the degree to which the item scores for the instrument conform to the hypothetical construct. Evidence based on relations to other variables concerns hypothesized relationships between the construct measured by the instrument and other variables within a specific theoretical framework. Accumulating this evidence requires information about the other variables of interest, gathered via additional tests or surveys of the respondents.

All the sources of evidence mentioned above provide support for instrument function from multiple perspectives. Gathering evidence, even for an existing instrument, is a long and iterative process and should never be viewed as complete. Instead of developing a new instrument from scratch, it is desirable to use and evaluate an established instrument for respondents in different contexts. While many instruments relating to attitude toward chemistry are available, five have been specifically evaluated with respect to published validity evidence in the college chemistry context (Arjoon et al., 2013): the Cognitive Expectations for Learning Chemistry Survey (CHEMX) (Grove & Bretz, 2007), Colorado Learning Attitudes about Science Survey (CLASS) (Barbera, Adams, Wieman, & Perkins, 2008), Chemistry Self-Concept Inventory (CSI) (Bauer, 2005), and Attitude toward the Subject of Chemistry Inventory (ASCI) (Bauer, 2008) and its shortened version ASCIv2. Among these instruments, ASCIv2 has the advantage of clear connection with the attitude definition and framework in psychology (Rosenberg & Hovland, 1960), which is supported by empirical data from student samples at multiple sites (Xu et al., 2012; Xu & Lewis, 2011). The ASCIv2 retains eight items from ASCI in two subscales, "intellectual accessibility" (items 1, 4, 5, and 10 from ASCI) about the difficulty of chemistry and "emotional satisfaction" (items 7, 11, 14, and 17 from ASCI) about how satisfied students feel about chemistry in general, which are congruent with two components (cognitive and affective, respectively) of attitude theory. This study focuses on quantitative analysis of internal structure, internal consistency, and some qualitative evidence based on response processes for

ASCIv2 in a new context, Saudi Arabia. These analyses were used to investigate the evidence that the ASCIv2 items are internally consistent and measuring the intended two attitudinal subscales for three student cohorts, thus providing a potential valid tool to support the cross-cultural attitudinal studies.

2 Research Questions

The goal of this study is to examine an attitude instrument, ASCIv2, which can be used to support cross-cultural studies for college chemistry programs. First, we are interested to see how ASCIv2 behaves for students with different backgrounds. We are also interested in examining the attitude profile across student groups.

The three specific research questions that guide the study are:

1. How did the attitude instrument function at a Saudi Arabian institution to measure the attitude construct, as compared to institutions in Australia and the USA regarding the construct validity and internal consistency reliability?
2. If there are any items performing differently at the Saudi Arabian institution, how did students interpret the problematic items?
3. What is the attitude status for students enrolled in general chemistry courses for a Saudi Arabian institution as compared to an Australia and a US institution?

2.1 Settings

A university in the Kingdom of Saudi Arabia, or KU, participated in this study. KU data was compared with those from SE, a southeastern university in the USA, and WU in Western Australia. Note that the attitude scores are for that specific university, and we cannot generalize from one university to the whole country. The detailed comparison of cultural, religious, and educational features in these three countries is beyond this report. Many factors can influence student attitude toward science including school, classroom, and family levels (Papanastasiou, 2002; Papanastasiou & Papanastasiou, 2004). Here we provide some general information about these three universities that could potentially affect how students respond to an attitude instrument, from differences in attitudinal status. Four similarities connect these universities: they are large in size, public, and research oriented (with high research activity), and the language of instruction is English. However, great distinctions exist in the school organization and the role of the chemistry course. KU ranks among the top four universities in Saudi Arabia according to the Academic Ranking of World Universities (ARWU) (Shanghai Jiao Tong University, 2012). With an acceptance rate of only 6.5 % based on internal institutional data during the recent years, KU accepts among the best 2 % of high school graduates, especially those who intend to study engineering disciplines. WU, on the other hand, has a different profile. It ranks among the top 20 out of 39 tertiary institutions in Australia (Australian Education Network, 2013) and is the largest university in its region. It is an internationally focused institution with 30–50 % international students. In the USA, the Carnegie Foundation for the Advancement of Teaching classifies institution characteristics, including students' prior academic preparation and selectivity of undergraduate admissions. SE is categorized as selective (Carnegie Foundation for the Advancement of Teaching, 2010). This category locates at roughly the middle two-fifths of baccalaureate institutions in the USA. As compared to the other two institutions, due to the relatively high ranking and selectivity of KU within Saudi Arabia, its students likely have good academic records, which may be associated with more positive attitudes (e.g., Brandriet, Xu, Bretz, & Lewis, 2012; Osborne et al., 2003, Xu, Villafane, & Lewis, 2013).

Additional distinctions between the institutions also are worth consideration. KU offers courses in the college of engineering, sciences, and industry management. The first major choice for most students is engineering. It is possible for students to change majors; however, few students do so. Social science or liberal arts programs are not available at the university, so there is not a diverse set of options. Since Saudi Arabian high school students are taught in different tracks (e.g., science/engineering vs. social science) starting in 11th grade, the KU students who enter the engineering major are mostly from the science/engineering track. Based on their high school experiences and institutional choice, entering KU students tend to have a good idea of chemistry and the importance of chemistry for their major when they take their first college chemistry course.

At WU, students are accepted for admission at university with a major; however, it is not unusual for students to consider changing their enrollment major or course of study. WU offers over 850 undergraduate and postgraduate courses in business, engineering, health sciences, humanities, science, mining, and agriculture. Students can change a major or add a second major at the beginning of semester at any point during their enrollment. Portability of courses between majors is encouraged through an established credit transfer system, and the commonality of chemistry as a first year course in many science-related majors means it is often taken by students in preparation for transfer to more competitive majors, such as Engineering or Pharmacy.

At SE, all students must officially declare a major or pre-major before they register for more than 36 credits, usually by the end of the second year. SE offers a balanced arts and sciences/professions undergraduate instructional program. During the first 2 years, students usually take general college courses that are applicable to all majors as they develop their knowledge of and perceptions about various major programs. A college general chemistry course, for example, can serve as a general course for both science and nonscience majors, meaning that students who may have been considering a science major can change their minds without penalty after taking chemistry. After the first 2 years, students enroll in the specific courses that apply toward completion of degree requirements for the chosen major. As compared to KU and WU, SE students may have a relatively vague idea about their major when taking their college general chemistry course and have more choices regarding major throughout the undergraduate period.

According to the university characteristics above, KU is the most selective among these universities, and KU students may understand best the importance of passing the college chemistry course for their degree, while SE is the least selective. We hypothesize that attitude follows the selectivity trend between KU and SE, with WU sitting in between. The participating universities also differ a great deal in the timing for students to declare a major and the options for changing majors, with KU students entering with significant experience in STEM-related courses and a relatively firm major choice and SE students entering without much experience and with the option to delay major choice until after taking chemistry. Again, we hypothesize that attitude would follow trend regarding major, with KU most positive, SE least, and WU in between.

3 Research Methods

3.1 Instrument

The English version of ASCIv2 was used at the three universities (Bauer, 2008; Xu & Lewis, 2011). The instrument is intended to measure students' attitude toward chemistry in general in a 7-point semantic differential format, e.g., chemistry is easy vs. hard for item 1 and comfortable vs. uncomfortable for item 4. It includes eight items which can be grouped in two subscales: intellectual accessibility (four items) and emotional satisfaction (four items). The entire instrument and instructions can fit on half a page, and it takes at most 5 min to administer. For a copy of the instrument, see the supplementary material (Xu & Lewis, 2011) or contact the corresponding author directly.

3.2 Participants and Data Collection

Detailed information about participants and data collection processes in Australia and the USA was provided in previous literature (Brandriet et al., 2012; Xu et al., 2012; Xu & Lewis, 2011). The participants at KU are all male students because KU is a single-sex public university in Saudi Arabia. All KU participants were majoring in Engineering, in keeping with the specialist nature of this institution.

Data were collected from freshman students enrolled in a section of the first semester General Chemistry course at KU in Saudi Arabia in February 2011. This section is taught in a traditional lecture-based way. There are a total of 190 students in the class. One hundred and seventy students returned the survey with complete data for all eight items and are included in the data analysis. We did not see any suspicious patterns in the missing data that could potentially bias the research findings.

3.3 Data Analysis

First, basic descriptive statistics including mean, standard deviation, skewness, and kurtosis for the eight items of ASCIv2 for KU students were obtained using SAS software version 9.1. In addition, a box-and-whisker plot was graphed for each item score, overlapped with the test items. A box-and-whisker plot is a convenient way to graphically indicate the degree of spread for each item through the seven values: the lowest score, the lower quartile (the score at the low 25 % rank in the sample), median (the score at the 50 % rank), upper quartile (the score at the high 25 % rank), and the highest score.

Next, evidence for reliability and validity of internal structure was examined. For reliability, Cronbach's alpha estimates were calculated using SAS 9.1. A high Cronbach's alpha suggests that the item scores are positively correlated with each other and with the total scale score as well. Cronbach's alpha of at least 0.7 is generally desirable for research purposes (Murphy & Davidshofer, 2005).

For validity evidence based on internal structure, confirmatory factor analysis was performed in Mplus 5.2 to estimate how well the designed two-factor correlated structure for the instrument fits the responses obtained with the sample (L. Muthén & B. Muthén, 2007). Fit indices such as chi-square (χ^2), Comparative Fit Index (CFI), and the Standardized Root Mean Square Residual (SRMR) were examined to assess the fitness of the model to the data, and item loadings were also evaluated. The criteria of CFI value greater than 0.95 and SRMR value less than 0.08 were used to indicate a good model fit and CFI $>$ 0.90 as acceptable fit (Bentler, 1990; Hu & Bentler, 1995).

When results raised concerns about items performing differently across the countries, we followed up by investigating how students interpreted the items. To achieve this, ASCIv2 was given to a group of students at KU who had previously completed the survey, to collect their written feedback about how they understood the problematic item. The feedback was independently coded to examine whether the item was interpreted as expected to indicate the intended subscale or not. The inter-rater reliability was calculated according to Cohen's kappa (Cohen, 1960). The widely used interpretation for the value of kappa is applied to examine the strength of agreement: $\leq$0.00 as poor, 0.00–0.20 as slight, 0.21–0.40 as fair, 0.41–0.60 as moderate, 0.61–0.80 as substantial, and 0.81–1.00 as almost perfect (Landis & Koch, 1977). Note that since students could not be asked to provide identification information, we could not match their initial answer on ASCIv2 with their feedback.

For the student feedback that did not capture the aspect of attitude intended by the subscale, three coders performed another round of open-ended coding to examine if any pattern existed. A code is any tag or label that assigns a sensemaking attribute for a portion of qualitative data (Miles & Huberman, 1994). Patterns in the codes were reported after the three coders reached consensus via discussion.

Finally, once validity and reliability evidence supported score interpretation, students' attitude scores from KU were compared with scores from WU and SE students, using a standard effect size method (Cohen, 1988). Cohen's *d* effect size can be used to quantify the difference in the attitude score. Values for Cohen's *d* of 0.2–0.3 are generally considered a "small" effect, of around 0.5 a "medium" effect, and of 0.8 or above a "large" effect. A medium effect size reflects a difference that would be noticeable to a careful observer.

4 Results

4.1 Descriptive Statistics for Item Scores for KU

Descriptive statistics are shown in Table 1 for each item (four reverse ordered items were reverse coded for interpretation). High scores mean that students feel chemistry is intellectually accessible and emotionally satisfying. The average scores range from 3.37 to 4.54, and standard deviations range from 1.39 to 1.92. No item was found to have skewness or kurtosis greater than 1.15, which suggests good normality of the item scores. From the items (6 and 8) with extreme scores in Table 1, students feel chemistry is organized and is challenging. This pattern is very similar with that observed for data from WU and SE (Brandriet et al., 2012; Xu et al., 2012; Xu & Lewis, 2011).

The box-and-whisker plot for each survey item for KU students is presented in Fig. 1. The star near the middle of box represents the mean score for each item, ranging from 3.37 for item 6 to 4.54 for item 8. The line near the middle of the box represents the median score for each item. Five items have a median at the middle point of 4, while items 5 and 8 have the median toward the positive side, with item 6 toward the negative side. The left and right of the box represent the lower and upper quartiles of the item score. For most items, students tend to pick between 3 and 5. The ends of the whiskers represent the minimum and maximum of all responses for each item. Note that the students used the full range; the whiskers extend from 1 to 7. From Fig. 1, most students tend to pick up the neutral attitude around 4, and there is a lot of overlap for the item scores.

Because the instrument has the internal structure of two subscales, we proceeded to examine the evidence based on the intended test design and interpret on the subscale level rather than on the item level.

Table 1 Descriptive statistics of item scores for KU

	Item		Mean	SD	Skewness	Kurtosis
1*	Hard	Easy	4.24	1.41	−0.24	−0.49
2	Complicated	Simple	3.89	1.39	−0.13	−0.65
3	Confusing	Clear	3.96	1.61	0.16	−1.05
4*	Uncomfortable	Comfortable	4.09	1.54	−0.11	−0.53
5*	Frustrating	Satisfying	4.41	1.57	−0.37	−0.56
6	Challenging	Not challenging	**3.37**	1.80	0.44	−0.81
7*	Unpleasant	Pleasant	4.08	1.92	−0.09	−1.15
8	Chaotic	Organized	**4.54**	1.67	−0.35	−0.81

Note: items with * are reverse coded but are shown with the word pairs also reversed for clarity of interpretation. The extreme values are in bold

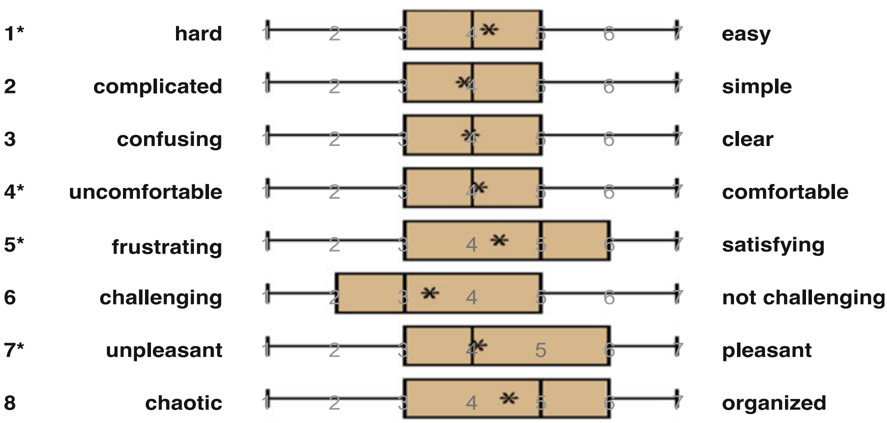

Fig. 1 Box-and-whisker plot for KU students overlapped with ASCIv2 items. Note that the item pairs have been reversed for items 1, 4, 5, and 7 for ease of interpretation

4.2 *Two-Factor CFA Model Fit*

CFA was performed to estimate an appropriate fit for the 2-factor model. Items 1, 2, 3, and 6 were set to load on the factor "intellectual accessibility" only; items 4, 5, 7, and 8 were set to load on the factor "emotional satisfaction" only, and the two factors were allowed to correlate. Models were identified by fixing the first item on its factor at 1.

The estimation of the 2-factor model fit for KU is χ^2 ($n = 170$, $df = 19$, $p < 0.001$) = 75, CFI = 0.88, SRMR = 0.07. Since CFI was less than 0.90, we can consider that the overall model does not fit the data well for the KU students. By comparison, the 2-factor model fit the data from WU and SE relatively well (Xu et al., 2012).

Item loading was examined to identify the source of the misfit for the KU data. As shown on Table 2, item 6 (regarding whether chemistry is challenging/not

Table 2 CFA item loadings for the two-factor solution and item-total correlation within each intended subscale

Factor	Item #	Item loading	Item-total correlation
Intellectual accessibility	Item 1	0.76	0.49
	Item 2	0.80	0.60
	Item 3	0.66	0.50
	Item 6	−0.11 (n.s.)	−0.04
Emotional satisfaction	Item 4	0.75	0.61
	Item 5	0.71	0.63
	Item 7	0.74	0.61
	Item 8	0.52	0.45

Note: all loadings are significantly different from 0 at the $\alpha = 0.05$ level except those labeled (n.s.)

challenging) is negatively related to other items in that scale of intellectual accessibility, and the correlation coefficient is not significantly different from zero. This means that KU students did not consider item 6 as an indicator of this proposed factor (intellectual accessibility), and the measurement of this scale should be reconstructed. The other scale of emotional satisfaction works as intended. For WU and SE data, all items are loaded on the intended subscale well. The item-total correlation was examined with item 6 (challenging vs. not challenging) and found to have an extremely low value of −0.1. Again the observation suggests that KU responses to item 6 are not correlated to three other items (1, 2, and 3) for the "intellectual accessibility" subscale. One possible reason is that KU students might have a different understanding of this word pair of challenging/not challenging from students at WU and SE.

4.3 Internal Consistency Reliability for ASCIv2

The internal consistencies were calculated for each subscale. Cronbach's alpha for the KU data is only 0.56 for the intellectual accessibility scale, which is quite a bit lower than the satisfactory level of 0.7. Cronbach's alpha increases to 0.78 if item 6 is deleted from this scale. Cronbach's alpha for both subscales for WU and SE are above the rule-of-thumb satisfactory level of 0.7.

4.4 Students' Interpretation of Item 6

Based on the CFA and Cronbach's alpha, KU students responded to item 6, challenging/not challenging, differently from their counterparts and were not consistent with the intended internal structure. It is critical to examine the cognitive process of how the respondents respond to the survey item, and the first task is to explore how

Table 3 Inter-rater agreement data for whether an interpretation of item 6 is a good indicator of the intended scale

		Rater 2		
A good indicator or not		Yes	No	Total for rater 2
Rater 1	Yes	40	1	41
	No	3	6	9
	Total for rater 1	43	7	50

respondents interpret the survey item (Schwarz, 1999). Specifically, we need to know whether students understand and respond to item 6 as an indicator of chemistry attitude on the intellectual accessibility subscale as expected.

Fifty KU students who took the ASCIv2 were willing to provide anonymous written responses to the second author regarding their interpretation of the meaning of item 6. The first author and a chemistry graduate student with qualitative coding experience independently coded all the feedback. If the student interpreted item 6 as expected for the intellectual accessibility scale, the feedback was coded as 1. If not, the code was 0. From Table 3, both raters agreed on 46 out of the 50 total codes, with percent agreement at 92 %. Inter-rater reliability calculated by Cohen's kappa is 0.70, which is considered substantial strength of agreement (Landis & Koch, 1977).

Both raters believed that a large portion of students (40/50) interpreted item 6 to involve considerations of whether chemistry is difficult or not, which does fit the intended scale of intellectual accessibility. Both raters also agreed that six students did not interpret the item as a good indicator of the intended subscale, but they disagreed on the other four students' feedback. Overall, then, ten students explicitly interpreted this item in terms that seemed outside intellectual accessibility to at least one rater.

Three chemistry graduate students engaged in a consensus coding process to identify the common characteristics in the ten student interpretations that were not in good alignment with the intended subscale. Out of the ten interpretations, one student interpreted the meaning of challenging as including strong negative emotional arousal. He wrote, "Challenging for me it means challenging (frustrating) in negative side of it, and usually frustrating does not lead to a positive result as far as what sort of despair and melancholy in the soul." This means he treats this item as more on the emotional satisfaction rather than on the intellectual accessibility subscale. Five student responses were in alignment with neither intended subscale. Three of these students interpreted item 6 as chemistry relating to daily life, for example, "Chemistry helps us to understand how the things around us work." The other two students viewed the item as indicating the role of chemistry in discovery, e.g., "Challenge in chemistry appears to me on how new discovery can help, improve, and solve of today life." These interpretations are both off target for intellectual accessibility.

The other four students mentioned multiple elements in their responses, such as the effort needed to learn chemistry, the lab work, competition for a high score, the learning strategy, the grading system, and so on. For example, one student wrote, "It let you try to do your best to get the best result; [e]specially in the lab you try to get the perfect result; however we can't, but we try our best." These interpretations are loosely connected to intellectual accessibility, but they also involve other ideas not intended by the subscale, so are too broad to really be on target.

Recently, we also have begun to collect cognitive interview data regarding how students at WU interpret and respond to ASCIv2 items. As for item 6, WU students have reported thinking about whether chemistry-related topics are difficult or easy, which is consistent with the intended construct of intellectual accessibility. While a few of the WU students also allude to emotions, in every case the emotion associated with "challenging" is positive, unlike the KU student's negative emotional connotation. For example, one student explicitly said: "I do not mean challenging in terms of overly difficult. I mean challenging in terms of it's something I enjoy getting involved in." These sorts of insights into how the items can be interpreted differently highlight the need for gathering evidence based on response processes, either via interviews or constructed response prompts.

4.5 Attitudinal Profile

Due to the problem of the unintended interpretation of item 6 for KU students, a slightly revised test structure of two factors measured by seven items without item 6 was considered for the purpose of interpretation. CFA was performed and Cronbach's alpha determined for each data set without item 6 to support this new score interpretation approach. As shown in Table 4, the model fits for the three data sets are all tenable without item 6. The model fit for KU improved when item 6 was removed. For the WU and the SE data, the model fit without item 6 remains good based on accepted fit criteria. For KU, the new Cronbach's alpha is 0.78 for the scale of intellectual accessibility and 0.77 for the scale of emotional satisfaction. The final Cronbach's alphas are 0.86 and 0.84 for the WU data and 0.80 and 0.79 for the SE data. All values are above the satisfactory level of 0.7.

We proceeded to calculate and compare the composite scores without item 6 for the two subscales for KU, WU, and SE. The intellectual accessibility composite score was obtained by averaging the three items 1, 2, and 3. The intellectual satisfaction composite score was the average of four items: 4, 5, 7, and 8. Cohen's *d* effect size is presented to quantify the difference in attitude between SE students and KU students (Table 5). Compared with the SE students, KU students think that chemistry is more intellectually accessible with the difference of 0.84 SD (a large effect size) and more emotionally satisfying with 0.53 SD (a medium effect size). The KU students feel chemistry is more intellectually accessible than WU students with a medium effect size and feel similarly on the scale of emotional satisfaction as WU.

Table 4 CFA model fit for the two-factor solution without item 6

Parameter	KU	WU	SE
χ^2	56.7	21	56
p-Value	<0.001	0.06	<0.001
df	13	13	13
CFI	0.90	0.98	0.96
SRMR	0.05	0.03	0.04

Table 5 Factor scores for each subscale for KU, WU, and SE

School	Subscale	α	Mean	SD	Effect size
KU ($n = 170$)	Accessibility	0.78	4.03	1.22	–
	Satisfaction	0.77	4.28	1.29	–
WU ($n = 108$)	Accessibility	0.86	3.56	1.20	0.39 (medium)
	Satisfaction	0.84	4.25	1.22	0.02 (no/trivial)
SE ($n = 354$)	Accessibility	0.80	3.04	1.16	0.84 (large)
	Satisfaction	0.79	3.63	1.20	0.53 (medium)

Note: all effect size comparisons are made with respect to KU

5 Discussion and Conclusions

This study reported results using the ASCIv2 attitude instrument for college students from three universities in Saudi Arabia, Australia, and the USA and successfully answered the research questions. First, based on the evidence analysis using Cronbach's alpha, confirmatory factor analysis, and student feedback about their response processes, the instrument of ASCIv2 measures attitude toward chemistry in a similar way across student groups with the exception of item 6. Care should be taken with using the same instrument in multiple countries, particularly when considering cultural interpretation of items that can influence validity. This study presents a case that a group of Saudi Arabian students, with a different background than two other groups of students, from Australia and the USA, respond to the survey items in a different pattern, even when the instrument language is the same.

Secondly, from the written feedback for KU students, we found ten students interpreted item 6 (challenging vs. not challenging) not as intended. Rather than considering the item as measuring intellectual accessibility, students aligned it with other unintended constructs. It is not clear what cued Saudi Arabian students to relate this item to daily life, discovery, strong negative emotions, or learning behaviors. Interestingly, four students from Australia respond to this item with positive emotion. Cognitive interviews or constructed responses from a larger student sample can help better understand the way student groups interpreted item 6 as related to their cultural background. Since the data in this study is all from KU males, further work with female students from Saudi Arabia is warranted. In addition, since the students in this study cannot be identified to track them, we do not know whether the 10 students with unintended interpretations were a large enough sample to influence the validity of score interpretation.

Last but not least, based on the composite score without item 6 for the intellectual accessibility subscale, we found that students enrolled in a general chemistry course at a US university exhibited a more negative attitude toward chemistry than their counterparts in Saudi Arabia and Australia. Effect sizes were large enough that the difference can be considered meaningful. This order in attitude is reasonable for these three institutions. SE ranks in the middle two-fifths of baccalaureate institutions in the USA and is not highly selective. In addition, SE students are not required to decide their major until after they take general chemistry and may not be prepared for nor committed to a STEM major. KU is a top engineering university in Saudi Arabia and very selective, and the students have already committed to STEM degrees before entering the university. Although it would not be appropriate to draw conclusions about national differences based on only one institution from each country, a similar order in attitude has been observed for middle school students: Saudi Arabian middle school students in general exhibit more positive attitudes toward science as measured by the index of Positive Affect Toward Science (PATS) on TIMSS as compared to Australian and US students (Martin et al., 2008). The need to foster positive attitudes toward chemistry, which is one central goal of science literacy as postulated by American Association for the Advancement of Science (1989), and to increase students' interest in the pursuit of STEM-related careers may inspire instructional interventions at SE and WA that may not be necessary for KU.

The use of a convenience sample from one university in each country limits generalizability for this study; however, the study represents an important initial step. As discussed, the Saudi Arabian university in this study is highly competitive and selective, and we may find that students at a less selective university are more similar to WU and SE students with respect to attitude or that KU students would be more similar to students at more selective universities in Australia and the USA. This study does show that ASCIv2 can be used to obtain interpretable attitude scores from students in multiple countries and that it can discriminate attitudinal differences.

As ASCIv2 becomes established as appropriate for cross-cultural use in studies such as these, we hope that this initial study has drawn attention to issues of item interpretation, and we believe that the principles and procedures described here can be useful to others engaged in similar work. For example, further psychometric evidence can be gathered for the international use of ASCIv2 in additional cultural contexts. If the problem for any instrument, such as the one with item 6, persists in multiple contexts, the problem can potentially be addressed by deleting the item from the instrument or by exploring alternative word pairs, with careful attention to the impact on validity of using the item to measure the intended construct.

Moreover, this study signifies the importance of examining psychometric evidence in context when an attitude instrument is used in cross-cultural scenarios, to ensure that responses in a new context still match the trait underlying the instrument and the comparison based on instrument scores is fair and sound. The administration of ASCIv2 in three countries makes us aware that, for validity in cross-cultural studies based on an instrument, the population may not share a similar background that cues participants to interpret items similarly, even when the language is the same. When instruments are translated and adapted to different languages, language factors alone can impact the test function and should be carefully examined (Allalouf, 2003; Roth, Oliveri, Sandilands, Lyons-Thomas, & Ercikan, 2012). With such efforts and evidence, we can have more confidence in conclusions of attitudinal differences by sex and/or ethnicity as posited by Osborne.

Once a robust instrument is chosen which works equally well for multiple groups with different backgrounds in the study setting, the next step is to use pre-post designs to track student attitude change in order to make fair cross-cultural attitudinal comparisons for college chemistry programs. Even with a robust instrument, we still must avoid the danger of determining program quality across countries based on one administration, because classes can be quite different. Other important variables, such as students' academic performance, class organizations, school environment, school curriculum, and institutional selectivity, need to be tracked and considered as potential confounds. Over time, with the accumulation of psychometric evidence for the cross-cultural use of attitude instruments, we can have more confidence in the understanding of attitude status and its relationship to other variables such as academic performance and curriculum. Accordingly, more effective curriculum innovations can be chosen based on evidence and then implemented to foster students' positive attitude while improving content learning.

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Secondary School Students' Chemistry Self-Efficacy: Its Importance, Measurement, and Sources

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Abstract Self-efficacy for learning chemistry refers to one's beliefs about his or her ability to successfully perform specific tasks in chemistry. For students to be successful in school chemistry, they need to have a positive sense of self-efficacy. Research has repeatedly indicated that individual students' levels of self-efficacy affect the effort they spend on an activity, the persistence they put forth when confronting obstacles, the resilience they show in the face of adverse situations, the level of academic achievement they attain, and the enrolment choices they make. Students construct their self-efficacy beliefs from four major sources of information: performance accomplishments, vicarious experiences, verbal persuasion, and physiological and emotional states. Although chemistry education researchers have developed several questionnaires to measure students' perceived self-efficacy, most of them are not specific enough to measure chemistry self-efficacy. Researchers have paid even less attention to investigating how classroom chemistry teaching contributes to the development of students' chemistry self-efficacy. This chapter provides an extensive review of the literature on chemistry self-efficacy, reports recent research on chemistry self-efficacy conducted in Hong Kong secondary schools, and offers some directions for future research on chemistry self-efficacy.

1 Introduction

There are many different affective variables influencing student learning in schools, such as attitudes, values, self-esteem, locus of control, self-efficacy, interest, aspirations, and anxiety (Anderson & Bourke, 2000). They differ in their target, direction, intensity, and level of specificity of measurement (Anderson & Bourke, 2000; Bandura, 1997; Wigfield & Eccles, 2000). At both the secondary and tertiary levels of study, students generally engage in certain learning tasks but try to avoid others. Why do students exhibit this kind of behavior? Bandura (1977, 1982) made

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a significant contribution to our understanding of human behavior when he introduced the construct of *self-efficacy* and social cognitive theory. Self-efficacy may be defined as people's beliefs about the extent to which they are capable of organizing and executing the courses of action required to produce given attainments (Bandura, 1997). It is more task- and situation-specific than, for example, self-concept (Pajares, 1996). According to social cognitive theory, people act based on their beliefs, values, thoughts, and goals (Bandura, 1986; Schunk, Pintrich, & Meece, 2008). Applied to science education, self-efficacy is concerned with a student's motivation toward science learning (Cavas, 2011) and beliefs about the future (Anderson & Bourke, 2000). It is a powerful determinant of how science students approach learning tasks and, therefore, what they will achieve in science. Unfortunately, empirical research on students' self-efficacy for learning chemistry in school is sparse when compared with research on other affective variables such as attitudes toward chemistry (Cheung, 2009a, 2009b; Menis, 1983) and interest in chemistry (Baram-Tsabari & Yarden, 2009). Researchers have paid even less attention to how teachers can help their students develop chemistry self-efficacy.

This chapter is organized into four sections. First, I present a rationale for the investigation of students' self-efficacy in the context of chemistry learning, focusing on the major effects of self-efficacy on student learning and behavior. I then review previous research on the measurement of chemistry self-efficacy and summarize the major limitations of previous research. Next, I discuss the four major sources of students' self-efficacy beliefs and illustrate my discussion with empirical research conducted in Hong Kong secondary schools. Special attention is paid to the relationships among chemistry self-efficacy, classroom teaching, chemistry achievement, and learning strategies. Finally, I conclude the chapter by offering some recommendations for future research on students' chemistry self-efficacy.

2 Importance of Self-Efficacy

Bandura (1993, 1997) theorized that self-efficacy beliefs affect how people feel, think, motivate themselves, and ultimately behave. Although self-efficacy is not equivalent to competence, there is considerable evidence to indicate that self-efficacy can positively influence task performance (Lynch, 2006; Merchant et al., 2012; Multon, Brown, & Lent, 1991; Robbins et al., 2004). Sometimes, knowledge, skill, and prior academic performance may not be strong predictors of subsequent performance because one's self-efficacy affects the ways in which he or she will behave when carrying out tasks. For example, Hackett and Betz (1989) found that the mathematics self-efficacy of undergraduates was more predictive of their selection of mathematics-related majors than their prior mathematics achievement. Zimmerman, Bandura, and Martinez-Pons (1992) reported that high school students' self-efficacy for academic achievement was more predictive of their final grades than their prior grades. Of course, academic self-efficacy and achievement may mutually affect each other, resulting in an upward spiral; self-efficacy enhances achievement, which in turn boosts self-efficacy, and so on. Individuals' self-efficacy mediates between their previous and subsequent academic attainments.

The meta-analysis conducted by Multon et al. (1991) found that, overall, self-efficacy beliefs can account for about 14 % of the variance in students' academic performance and about 12 % of the variance in their academic persistence. The percentages varied across types of research design, measures of academic achievement, students' ability levels, and types of schools. For example, experimental studies of self-efficacy treatments were found to explain 34 % of the variance in academic performance. Measures of academic performance included standardized achievement tests, course grades, and basic skill tasks. Academic persistence was measured by the time spent on task, number of tasks attempted, or number of academic terms completed.

Schunk (1981) randomly assigned 56 American elementary school students to experimental and control groups and discovered that the students' self-efficacy was an accurate predictor of their arithmetic performance as assessed by an achievement test. Bandura (1993) reported that when the students were selected at three levels of mathematical ability—low, medium, and high—those students with higher mathematical self-efficacy chose to rework more of the difficult problems given to them and obtained a higher percentage of accurate solutions, irrespective of ability levels. Hence, the students performed poorly in mathematics because they lacked the requisite skills or they possessed the skills, but they lacked the self-efficacy beliefs to use them effectively.

Hampton and Mason (2003) collected 278 American high school students' data on self-efficacy beliefs and academic achievement at two time points. With the aid of structural equation modeling, they found that self-efficacy was positively related to academic achievement obtained at the end of the semester. Lau and Roeser (2002) examined how cognitive abilities and motivational factors were associated with high school students' science achievement. The results of their hierarchical regression analyses indicated that the students' science self-efficacy positively predicted their science test scores ($\beta = 0.20$, $p < 0.01$), science grades ($\beta = 0.16$, $p < 0.05$), and choices of science majors and careers ($\beta = 0.16$, $p < 0.05$).

Furthermore, Areepattamannil, Freeman, and Klinger (2011) used hierarchical linear modeling to analyze the Canadian PISA data. They compared the effects of different student-level variables on science achievement, including enjoyment of science, general interest in science, instrumental motivation to learn science, future-oriented motivation to learn science, self-efficacy in science, and self-concept in science. They reported that science self-efficacy had the largest predictive effect on science achievement. Pajares (1996) also pointed out that

> Efficacy beliefs help determine how much effort people will expend on an activity, how long they will persevere when confronting obstacles, and how resilient they will prove in the face of adverse situations—the higher the sense of efficacy, the greater the effort, persistence, and resilience. Efficacy beliefs also influence individuals' thought patterns and emotional reactions. People with low self-efficacy may believe that things are tougher than they really are, a belief that fosters stress, depression, and a narrow vision of how best to

> solve a problem. High self-efficacy, on the other hand, helps to create feelings of serenity in approaching difficult tasks and activities. As a result of these influences, self-efficacy beliefs are strong determinants and predictors of the level of accomplishment that individuals finally attain. (Pajares, 1996, pp. 544–545)

This chapter focuses on *chemistry self-efficacy*, which refers to one's beliefs about his or her capability to successfully perform particular chemistry tasks or solve particular chemistry problems. Chemistry self-efficacy positively influences chemistry achievement by affecting students' learning process, including choice of learning activities, effort expenditure, persistence at tasks, and perseverance in the face of difficulties. Students with high chemistry self-efficacy are likely to try harder and persevere longer to perform challenging tasks, whereas students with low chemistry self-efficacy tend to exhibit the opposite.

Despite the fact that self-efficacy has become a pivotal affective construct in understanding student learning, empirical research on self-efficacy in the domain of chemistry education is sparse when compared with works in other domains such as mathematics education. Nevertheless, several researchers have documented that self-efficacy can predict students' chemistry achievement in high school and university (Kan & Akbaş, 2006; Merchant et al., 2012; Zusho, Pintrich, & Coppola, 2003) and enrolment choices (Dalgety & Coll, 2006a). For example, Zusho et al. (2003) investigated how student self-efficacy changed over the course of one semester and how it related to chemistry achievement. The participants were 458 students enrolled in introductory chemistry courses at a university in the USA. They adapted seven items from the motivated strategies for learning questionnaire to measure students' self-efficacy at three time points over the course of one semester. They found that students' self-efficacy declined over the course of the semester, and the decline seemed to be most obvious among the low achievers. Interestingly, perceived self-efficacy was the best predictor of final course grades even after controlling for prior achievement. This finding is consistent with those found by the researchers such as Bandura, Adams, and Beyer (1977). Initially, people rely on their past performance in judging their levels of self-efficacy. However, as they develop their self-efficacy through further experience, their subsequent performance attainments will be more strongly determined by their self-efficacy than by their past performance (Bandura, 1993). Zusho et al. (2003) also found that students with higher levels of self-efficacy reported using more deep learning strategies such as metacognition and elaboration. Other researchers (e.g., Schmidt & Ford, 2003) have documented similar findings in other subject areas.

Merchant et al. (2012) investigated the impact of a 3D desktop virtual reality environment on the learning of the valence shell electron pair repulsion (VSEPR) theory in an introductory chemistry class. Their sample consisted of 204 undergraduates enrolled in a chemistry course at a university in the USA. They used 11 - multiple-choice questions to assess the students' understanding of molecular angles, molecular geometry, and species identifications. They also constructed 15 items to measure the students' self-efficacy for learning VSEPR theory. The students' self-efficacy was found to positively relate to their scores on the multiple-choice test.

In New Zealand, Dalgety and Coll (2006a) investigated university students' reasons behind enrolment choices. They measured chemistry self-efficacy with a questionnaire consisting of 17 items. They found that there was a statistically significant difference in chemistry self-efficacy between students intending to enroll and not intending to enroll in chemistry the following semester. This finding was supported by qualitative interview data and indicated that if students had low self-efficacy beliefs about chemistry, they were less likely to enroll a chemistry course.

3 Measurement of Chemistry Self-Efficacy

An important area in chemistry self-efficacy research concerns the measurement of the self-efficacy construct. Researchers have developed several instruments to measure students' self-efficacy for learning science (e.g., Glynn, Brickman, Armstrong, & Taasoobshirazi, 2011; Thomas, Anderson, & Nashon, 2008; Tuan, Chin, & Shieh, 2005; Velayutham, Aldridge, & Fraser, 2011). It is important to note that self-efficacy is a domain- and task-specific construct; beliefs in one's efficacy can vary across different science disciplines such as physics, chemistry, earth science, and biology. For example, a student may have high self-efficacy in chemistry but low self-efficacy in physics, leading to different patterns of behavior when studying these two subjects in school. Even for school chemistry, beliefs in one's efficacy can vary across topics (e.g., atomic structure vs. the mole concept) because chemistry self-efficacy is a specific estimate of confidence in one's capability to successfully perform particular chemistry tasks or solve particular chemistry problems.

An empirical study of mathematics self-efficacy by Pajares and Miller (1995) confirmed that the measurement of self-efficacy should be specific in order to increase its predictive value. The measure should be tailored to the criterion task under investigation and the domain of functioning being analyzed. In other words, if we want to measure students' chemistry self-efficacy and investigate its power to predict their test scores on a particular chemistry topic (e.g., chemical equilibrium), we should try to construct items that can validly and reliably measure the students' self-efficacy for learning that topic rather than constructing items to measure general self-perceptions of chemistry learning. Self-efficacy is an individual's situation-specific beliefs about the future. According to the literature review conducted by Pajares (1996), previous studies that reported a lack of relation between self-efficacy and performance often suffered from problems either in specificity or correspondence. As a cautionary remark, if self-efficacy is measured at a domain—rather than at a task level of specificity—then self-efficacy will be difficult to distinguish from self-concept (Skaalvik & Skaalvik, 2009).

3.1 Measurement of General Chemistry Self-Efficacy

Many researchers have constructed items and surveys to measure general chemistry self-efficacy (see Table 1). In the paragraphs that follow, I briefly review those surveys. For example, in the USA, Smist (1993) used six questionnaire items to measure a sample of college students' self-efficacy for learning chemistry. The items were administered to the students before and after they took a freshman general chemistry course. The internal consistency of data was high (Cronbach's $\alpha = 0.90$), but the six items were not constructed to measure students' self-efficacy for learning specific chemical concepts.

In New Zealand, Coll, Dalgety, and Salter (2002) developed fairly broad items to measure first-year university students' self-efficacy for learning chemistry. Their revised version of the questionnaire consisted of 17 items with a 7-point semantic differential format (Dalgety et al., 2003; Dalgety & Coll, 2006a, 2006b). Sample

Table 1 Examples of items measuring general chemistry self-efficacy

Source	Instruction and sample item	Response format
Smist (1993)	How much confidence do you have about doing each of the behaviors listed below? [6 chemistry tasks listed, e.g., "getting good grades in chemistry," "doing chemistry homework problems well," "understanding abstract chemical concepts"]	5-point rating scale from A (quite a lot) to E (very little)
Dalgety, Coll, and Jones (2003)	Please indicate how confident you feel about [followed by 17 statements, e.g., "applying a set of chemistry rules to different elements of the periodic table," "achieving a passing grade in a chemical hazards course," "tutoring another student in a first-year chemistry course"]	7-point semantic differential format with the paired adjectives "not confident" and "totally confident"
Çapa Aydin and Uzuntiryaki (2009)	Please indicate your opinion about each of the statements below [16 statements presented, e.g., "How well can you define the fundamental concepts in chemistry?" "How well can you choose an appropriate formula to solve a chemistry problem?" "How well can you collect data during the chemistry laboratory?"]	9-point rating scale from 1 (very poor) to 9 (very well)
Uzuntiryaki and Çapa Aydin (2009)	Please indicate your opinion about each of the statements below. [21 statements presented, e.g., "To what extent can you explain chemical laws and theories?" "How well can you work with chemicals?" "To what extent can you propose solutions to everyday problems by using chemistry?"]	9-point rating scale from 1 (very poor) to 9 (very well)

items are shown in Table 1. In a pilot study, Dalgety et al. (2003) conducted an exploratory factor analysis of the data collected by the 17 items and yielded four factors: learning chemistry theory self-efficacy, applying chemistry theory self-efficacy, learning chemistry skills self-efficacy, and applying science skills self-efficacy. However, exploratory factor analyses of data from a validation study generated only one factor. Therefore, further research is needed to investigate the factor structure of the 17-item instrument.

In Turkey, Çapa Aydin and Uzuntiryaki (2009) developed a 16-item high school chemistry self-efficacy scale. Their sample consisted of 362 tenth-grade chemistry students. Confirmatory factor analysis of the data resulted in satisfactory fit with two factors. The first factor concerned chemistry self-efficacy for cognitive skills (10 items, Cronbach's $\alpha = 0.90$). It refers to the students' beliefs in their ability to use some general intellectual skills in chemistry. Sample items are shown in Table 1. The second factor concerned self-efficacy for the chemistry laboratory (6 items, Cronbach's $\alpha = 0.92$). It refers to the students' beliefs in their ability to accomplish some generic laboratory tasks including skills in both cognitive and psychomotor domains. The correlation between these two factors was 0.61. In a related study, Uzuntiryaki and Çapa Aydin (2009) deleted one item from the high school chemistry self-efficacy scale and added six items to form the college chemistry self-efficacy scale. They used confirmatory factor analysis and found three rather than two dimensions underlying their scale: self-efficacy for cognitive skills, self-efficacy for psychomotor skills, and self-efficacy for everyday applications.

3.2 *Measurement of Topic-Specific Chemistry Self-Efficacy*

Relatively fewer surveys have been constructed to measure topic-specific chemistry self-efficacy. For example, in the USA, Merchant et al. (2012) made a good attempt to construct specific questionnaire items to measure chemistry self-efficacy. They investigated the impact of a 3D desktop virtual reality environment on the learning of the valence shell electron pair repulsion (VSEPR) theory in an introductory chemistry class. The sample consisted of 204 undergraduates enrolled in a chemistry course at a university. They constructed 15 items to measure the students' self-efficacy for learning VSEPR theory and asked the students to rate each item on a 5-point Likert scale (from 1 = strongly disagree to 5 = strongly agree). Example items are "I am confident I have the ability to learn the material taught about VSEPR theory," "I am confident I can do well on the exam questions about VSEPR theory," "I can characterize a molecule or ion as obeying or disobeying the octet rule," "I am confident I can do well on the lab experiment dealing with VSEPR theory," and "I am confident that I could explain the concepts on VSEPR theory learned in this class to another person." The data were of high reliability (Cronbach's $\alpha = 0.93$), and the confirmatory factor analysis indicated good fit for a one-factor model.

Table 2 Items measuring Hong Kong students' chemistry self-efficacy in 2010

Without reviewing textbooks and notes, are you confident that you can complete the following chemistry tasks? Please rate your degree of confidence by recording in each of the blank spaces a number from 0 to 100 using the scale below

0	10	20	30	40	50	60	70	80	90	100
Cannot do at all					Moderately certain can do					Highly certain can do

	Item	*M*	SD	Skewness	Kurtosis
1	Predict the chemical properties of some unfamiliar elements in the periodic table	57.25	22.57	−0.03	−0.72
2	State the meaning of the chemical symbol ${}^{23}_{11}Na$	71.64	23.05	−0.71	0.22
3	Draw the electron diagram of Ca^{2+} ion	89.85	12.65	−1.06	0.04
4	Deduce the formulas for ionic compounds with known cations and anions	78.12	18.67	−0.55	−0.88
5	Construct formulas of ionic compounds based on their names	71.55	19.18	−0.18	−0.87
6	Explain the differences in physical properties between ionic and covalent substances	72.73	21.73	−0.77	0.73
7	Predict the formula and structure of a compound when the group numbers of the two constituent elements are given	66.97	18.58	0.09	−0.41
8	Draw electron diagrams to show the double covalent bonds in a carbon dioxide molecule	85.45	18.00	−1.03	−0.13
9	Write word equations for the reactions of metals and dilute hydrochloric acid	78.64	18.89	−0.10	−1.65
10	Convert word equations to balanced chemical equations	74.76	17.88	−0.34	−0.41
11	Write the balanced chemical equation for the reaction between calcium and water	78.67	17.52	−0.37	−0.86
12	Use examples to explain the conditions under which displacement reactions occur	74.55	20.78	−0.60	−0.54
13	Write balanced ionic equations	76.21	17.77	−0.52	−0.20
14	Construct a reactivity series for some metals based on experimental results	73.82	19.81	−0.13	−1.21
15	Explain why rusting of underground iron pipelines can be prevented by sacrificial protection	77.27	21.06	−0.66	−0.11

In 2010, I designed a questionnaire to survey Hong Kong students' self-efficacy for learning five specific chemistry topics: periodic table, ionic bonding, covalent bonding, writing balanced chemical equations, and chemical properties of metals (see Table 2). The purpose of my study was to determine what content was difficult for students to learn. In Hong Kong, secondary schooling consists of 6 years (referred to as Secondary 1–6). Chemistry is offered as an elective subject to Secondary-4–6 students (aged about 16–18 years). The academic year in Hong Kong begins in September. These five topics are typically taught in Secondary-4 chemistry during the period from September to December. I invited a chemistry teacher to participate in my pilot study and surveyed his class of Secondary-4 students ($N = 33$) in December 2010.

I used the response format described in Bandura (2006) when designing my questionnaire. The students responded to each task by writing their answers using ratings that ranged from 0 to 100 in 10-unit intervals. Written labels were provided beside the following points: 0 (cannot do at all), 50 (moderately certain can do), and 100 (highly certain can do). Because self-efficacy is concerned with perceived capability, the items were phrased in terms of *can do* rather than *will do* (Bandura, 2006).

The internal consistency of the student data was high (Cronbach's $\alpha = 0.93$). Some descriptive statistics are displayed in Table 2. Students expressed high levels of self-efficacy for tasks that relied on memorization or that had been practiced significantly in class (e.g., drawing electron diagrams of ions and molecules). Chemistry courses in Hong Kong schools are often rife with memorization. Some students, unable to memorize chemical formulas or properties of elements, expressed lower levels of self-efficacy for tasks that required them to apply learned information in unfamiliar contexts (e.g., predict the chemical properties of some unfamiliar elements in the periodic table; predict the formula and structure of a compound when the group numbers of the two constituent elements are given). The participating classroom teacher found these results to be particularly informative for his teaching.

4 Sources of Self-Efficacy

Students have to approach academic tasks in chemistry with confidence. How can teachers help their students develop confidence? According to Bandura (1977, 1982, 1997), students construct their self-efficacy beliefs in a given domain of activity based on information from four major sources: performance accomplishments, vicarious experiences, verbal persuasion, and physiological and emotional states. In the paragraphs that follow, I discuss each of these sources. It is important to note that the information from these four sources is not, by itself, diagnostic of a student's self-efficacy; such information influences perceived self-efficacy through cognitive processing, and the interpretation of information is affected by many internal and environmental factors (Bandura, 1997).

Performance accomplishments refer to students' actual experiences of success in task performances. In general, repeated successes in a specific task of concern raise self-efficacy and failures lower self-efficacy in the particular domain of interest. Very often, performance accomplishments are the most influential source of information (Arslan, 2012; Britner & Pajares, 2006; Kiran & Sungur, 2012; Klassen, 2004; Luzzo, Hasper, Albert, Bibby, & Martinelli, 1999; Usher & Pajares, 2006) because they provide the most authentic evidence of mastery experiences. But self-efficacy, which is influenced by more than prior attainments, is often the best predictor of final attainments even after controlling for prior attainments (Bandura, 1993; Zusho et al., 2003), because it influences the learning goals students will set for themselves. Students with higher self-efficacy tend to set more challenging learning goals for themselves when studying a school subject.

Vicarious experiences refer to experiences gained by watching others doing something. Modeling is an effective source of information for promoting a sense of personal self-efficacy, particularly when the observer and the target person have similar characteristics (Bandura, 1997). Students who observe peers performing a task successfully are likely to believe that they, too, can accomplish it. In addition to peers, there are other sources of modeling, including symbolic modeling provided by visual media such as television and videos (Schulz & McDonald, 2011).

Verbal persuasion refers to persuasion that one can perform a task by a trustworthy source such as the classroom teacher. Telling students that they are making progress in learning chemistry may enhance their self-efficacy beliefs about this school subject, but the feedback must be specific so that chemistry students can adequately recognize the cause of their success. For example, a student conducted an inquiry-based chemistry experiment and submitted her written laboratory report. The teacher discovered that the quality of her written report had improved dramatically, particularly the conclusion section. The teacher praised the student for mastering the assessment criteria (Cheung, 2006) when writing the conclusion.

Physiological and emotional states refer to how students feel before, during, and after engaging in a task. Students will evaluate the inferences from physiological and emotional reactions (e.g., rapid heart rate, trembling, sweating) associated with a task. To enhance chemistry self-efficacy, students must not be overwhelmed with negative physiological or emotional reactions.

The effectiveness of the above four sources of self-efficacy information has been demonstrated by researchers (Hampton & Mason, 2003; Koh & Frick, 2009; Lopez, Lent, Brown, & Gore, 1997; Özyürek, 2005; Tang et al., 2004; Usher, 2009; Usher & Pajares, 2008). For example, research by Hampton and Mason (2003) found that the four sources of efficacy were positively associated with American high school students' self-efficacy for tasks in classroom and for organizing school-related activities. Usher (2009) interviewed eight middle school students to determine their sources of self-efficacy in mathematics. She reported that the students relied on self-efficacy from all the four sources hypothesized by Bandura (1977, 1997).

The work of Sawtelle, Brewe, and Kramer (2012) revealed that there might be gender differences in the effects of the four sources of information. They found that the success of male students in an introductory physics course was predicted by performance accomplishment experiences alone, but only vicarious experience was a significant predictor of female student success.

4.1 Measuring Students' Perceptions of the Sources of Their Self-Efficacy

Mathematics educators have conducted a lot of research in this area and published their instruments (Klassen, 2004; Lent, Lopez, & Bieschke, 1991; Matsui, Matsui, & Ohnishi 1990; Usher & Pajares, 2009). For example, Lent et al. (1991) designed 40 items to study mathematics students' perceived sources of self-efficacy information. The participants were 138 undergraduate students. They were asked to indicate their level of agreement with each item on a 5-point scale. Half of the 40 items were negatively worded and reverse scored. The 40 items formed four 10-item scales (Usher & Pajares, 2008), corresponding to the four sources of self-efficacy hypothesized by Bandura (1977, 1997): personal performance accomplishments (e.g., "I received good grades in my high school math classes," "I have always had a natural talent for math," "I got a high grade in last year's math class"); vicarious learning (e.g., "My favorite teachers were usually math teachers," "In mathematics class, I rarely get the answer before my classmates do," "My friends tend to avoid math assignments"); social persuasion (e.g., "My friends have discouraged me from taking math classes," "People often tell me that I am good at math," "My teachers believe I can do well in math courses"); and emotional arousal (e.g., "I get really uptight while taking math tests," "My mind goes blank, and I am unable to think clearly when trying to do math"). Lent et al. (1991) reported that the four scales were significantly interrelated and had internal consistencies ranging from 0.56 to 0.90. They found that the efficacy informational sources could help to predict and explain gender differences in mathematics self-efficacy; the bivariate correlations of each source with mathematics self-efficacy were significant except for the correlation between vicarious experience and mathematics self-efficacy in women. Results of factor analyses of the data on the four sources can be found in Lent, Lopez, Brown, and Gore (1996).

Britner and Pajares (2006) adapted the instrument used by Lent et al. (1996) to form a 31-item sources of science self-efficacy scale. They kept the four subscales when surveying students in grades 5–8 in a middle school in the USA. Sample items are "I got a good grade in science class last semester," "Many of the adults I most admire are good in science," "My teachers believe I can do well in difficult science courses," and "Science makes me feel uncomfortable and nervous." Only mastery experiences significantly predicted students' science self-efficacy. In Turkey, Kiran and Sungur (2012) also adapted the mathematics instrument to form a 33-item scale to measure eighth grade students' sources of self-efficacy in science. Sample items are "My favorite teachers were usually science teachers" and "I get a sinking feeling when I think of trying to solve hard science problems." Only mastery experiences, verbal persuasions, and emotional arousal were found to be significantly related to students' science self-efficacy.

Fencl and Scheel (2005) reported the use of a 33-item survey called sources of self-efficacy in science courses—physics (SOSESC-P). The items formed four subscales: performance accomplishments (10 items), vicarious learning (7 items), verbal encouragement/social persuasion (7 items), and emotional arousal (9 items). Sample items are "I can remember the basic physics concepts taught in this class," "My instructor's demonstrations and explanations gave me confidence that I could solve physics-related problems," "The instructor in this course encouraged me to put forth my best efforts," and "I usually didn't worry about my ability to solve physics problems" (H. Fencl, personal communication, February 19, 2013). Physics students were asked to rate each item on a 5-point Likert scale (from 1 = strongly disagree to 5 = strongly agree). Results of factor analysis of SOSESC-P data were not published. Fencl and Scheel (2005) found that teaching strategies such as collaborative learning, question and answer, electronic applications, and conceptual problem assignments were positively correlated with students' perceived sources of physics self-efficacy. Recently, Sawtelle et al. (2012) used the 33-item SOSESC-P to study the self-efficacy of students in the introductory physics classes at Florida International University. Internal consistency of data collected by the four subscales ranged from 0.68 to 0.88. They found that among the four sources of information on self-efficacy, vicarious learning experiences had a significant effect on predicting the retention of women in physics, whereas the success of men in physics could be predicted by mastery experiences alone.

Usher and Pajares (2008) conducted an extensive review of methods to measure sources of self-efficacy, but their focus was not on chemistry or science self-efficacy. To my knowledge, no published research has been conducted to examine secondary school students' sources of chemistry self-efficacy. Therefore, in November 2011, I extended my pilot study to investigate Hong Kong students' sources of chemistry self-efficacy. My investigation was guided by three research questions: (1) Which instructional aspects of regular teaching in the chemistry classroom can provide the four sources of self-efficacy information as described by Bandura (1977, 1997)? (2) How is students' chemistry self-efficacy affected by the four sources of information? (3) What is the effect of students' chemistry self-efficacy on their chemistry achievement? The participants ($N = 606$) were Secondary-4 chemistry students from 10 schools in Hong Kong. Data screening resulted in an effective sample size of 580.

Efficacy-Enhancing Teaching Because the effectiveness of Bandura's (1977, 1997) four sources of self-efficacy information has been demonstrated by research, I hypothesized that *efficacy-enhancing teaching*, as will be explained in greater detail below, can boost students' chemistry self-efficacy. Efficacy-enhancing teaching refers to the use of instructional strategies during regular chemistry teaching, which can provide students with performance accomplishments, vicarious experiences, verbal persuasions, and positive physiological states. Specifically, efficacy-enhancing teaching consisted of the following instructional strategies in my Hong Kong study:

- Performance accomplishments—teach students how to find main ideas to solve chemistry problems successfully.
- Vicarious experiences—provide students with opportunities to learn from classmates.
- Verbal persuasion—praise students who are showing improvement on their learning; tell students that they have the capability to learn chemistry better.
- Physiological and emotional states—encourage low-achieving or shy students to participate in the learning process, provide students with a friendly learning environment, and encourage students to ask and answer questions.

Eight items were used to measure student perceptions of the implementation of efficacy-enhancing teaching in the chemistry classroom. They were prefaced with the heading "In the Secondary-4 chemistry lessons since September 2011," and students were asked to rate each item on a 4-point scale (from 1 = never to 4 = in most lessons). The data on efficacy-enhancing teaching were of high reliability ($\alpha = 0.87$). The AMOS software program (Byrne, 2010) was used to assess the univariate skewness and kurtosis of each item, as well as the joint multivariate kurtosis. As can be seen in Table 3, the univariate skewness and kurtosis were low, but the joint distribution was multivariately non-normal. Thus, confirmatory factor analysis was conducted using the asymptotic distribution-free estimation in AMOS. The ability of a one-factor model to fit data was evaluated using the chi-square (χ^2), the goodness-of-fit index (GFI), the adjusted GFI (AGFI), the Tucker-Lewis index (TLI), the comparative fit index (CFI), and the root mean square error of approximation (RMSEA). Because the χ^2 statistic is sensitive to sample size, I based the evaluation of model fit on the considerations of multiple indexes and beyond the statistical significance of the χ^2. According to conventional criteria, an acceptable fit is indicated by $GFI > 0.90$, $AGFI > 0.90$, $TLI > 0.90$, $CFI > 0.90$, and $RMSEA < 0.08$ (Schumacker & Lomax, 2010). Confirmatory factor analysis of the Hong Kong student data indicated mediocre fit for a one-factor model ($\chi^2 = 53.937$, $df = 20$, $p < 0.001$, $GFI = 0.963$, $AGFI = 0.934$, $TLI = 0.803$, $CFI = 0.859$, $RMSEA = 0.054$) because TLI and CFI were below the preferred value. Research is being conducted to improve the items.

Chemistry Self-Efficacy The second measure aimed to assess students' self-efficacy for learning school chemistry. To make my self-efficacy scale domain specific and task specific, I selected five items from Table 1 that matched the

Table 3 Descriptive statistics for the efficacy-enhancing teaching items

Item		*M*	SD	Skewness	Kurtosis
1.	My teacher encouraged us, particularly shy students, to answer questions	2.92	0.84	−0.46	0.25
2.	I had opportunities to learn from classmates with better achievement to help me understand chemical concepts	2.90	0.87	−0.46	−0.42
3.	My teacher taught us how to find main ideas to solve chemistry problems successfully	3.13	0.80	−0.65	−0.07
4.	My teacher particularly encouraged students with lower academic achievement and provided them with opportunities to participate in learning	2.82	0.90	−0.32	−0.68
5.	My teacher praised students who were showing improvement and encouraged others to learn from them	2.91	0.84	−0.41	−0.41
6.	My teacher encouraged us to ask questions	2.97	0.86	−0.55	−0.29
7.	My teacher said that we have the capability to learn chemistry better	2.93	0.93	−0.57	−0.51
8.	My teacher provided us with a friendly learning environment and encouraged us to ask questions freely	3.09	0.88	−0.77	−0.05

Note: Multivariate kurtosis = 14.50 and its critical ratio = 13.81

chemistry topics learned by Hong Kong Secondary-4 students in September–November 2011. The items were prefaced with the heading "I am confident that I can," and students were asked to rate each item on a 6-point scale (from 1 = highly unconfident to 6 = highly confident). Table 4 shows the five items and descriptive statistics. The student data were of high reliability ($\alpha = 0.93$). Because the joint distribution was multivariately non-normal, confirmatory factor analysis was performed by AMOS using the asymptotic distribution-free method and indicated good fit for a one-factor model ($\chi^2 = 13.090$, df = 5, $p < 0.05$, GFI = 0.986, AGFI = 0.959, TLI = 0.948, CFI = 0.974, RMSEA = 0.053).

Chemistry Achievement When I conducted the survey in November 2011, the information about the students' test or examination scores in Secondary-4 chemistry was not available from schools. Thus, an item was included in the questionnaire to elicit from students their perceived level of chemistry achievement when compared with classmates. The item was accompanied by five alternatives, ranging from 1 (very poor), 2 (poor), 3 (average), 4 (good), to 5 (very good).

Using structural equation modeling, I tested a model of chemistry self-efficacy, and the standardized solution is shown in Fig. 1. Because the data were multivariately non-normal, the model was tested using the asymptotic distribution-free method in AMOS. The fit for the hypothesized model was mediocre ($\chi^2 = 163.756$, df = 76, $p < 0.001$, GFI = 0.935, AGFI = 0.910, TLI = 0.826, CFI = 0.855, RMSEA = 0.045) because TLI and CFI were below the preferred value. Efficacy-enhancing teaching was positively associated with chemistry self-efficacy ($\beta = 0.38$, $t = 7.4$, $p < 0.001$). The relationship between efficacy-enhancing teaching and chemistry self-efficacy was fairly strong; for every unit increase in efficacy-enhancing teaching, the degree of chemistry self-efficacy became greater

Table 4 Descriptive statistics for the self-efficacy items

Item		*M*	SD	Skewness	Kurtosis
1.	Construct formulas of ionic compounds based on their names	4.20	1.37	−0.56	−0.35
2.	Draw electron diagrams to show the double covalent bonds in a carbon dioxide molecule	4.41	1.44	−0.64	−0.51
3.	Convert word equations to balanced chemical equations	4.28	1.43	−0.63	−0.43
4.	Write the balanced chemical equation for the reaction between calcium and water	4.24	1.46	−0.54	−0.60
5.	Write balanced ionic equations	4.14	1.47	−0.51	−0.64

Note: Multivariate kurtosis = 12.24 and its critical ratio = 17.61

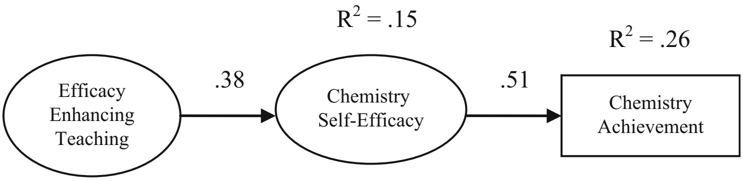

Fig. 1 Standardized solution for the chemistry self-efficacy model. *Note:* The two path coefficients are significant at the 0.001 level

by 0.38 unit. In other words, chemistry students who reported that their teachers often provided them with opportunities to succeed, to learn from classmates, to receive verbal persuasion, and to study in a friendly learning environment tended to have higher levels of chemistry self-efficacy than those who reported that their teachers seldom did so. This finding is consistent with previous research (e.g., Lopez et al., 1997) on the sources of self-efficacy.

Figure 1 also shows that chemistry self-efficacy was strongly related to chemistry achievement ($\beta = 0.51$, $t = 13.4$, $p < 0.001$). Thus, consistent with the previous research (e.g., Areepattamannil et al., 2011; Britner & Pajares, 2006; Hampton & Mason, 2003; Lau & Roeser, 2002; Schunk, 1981), Hong Kong students who reported higher levels of chemistry self-efficacy had higher chemistry achievement than those who reported lower levels of self-efficacy. The squared multiple correlation for chemistry achievement was 0.26, indicating that 26 % of the variance-associated chemistry achievement was accounted for by chemistry self-efficacy.

Although the use of efficacy-enhanced teaching methods was positively related to increased levels of chemistry self-efficacy, the squared multiple correlation for chemistry self-efficacy was 0.15 (see Fig. 1), indicating that only 15 % of the variance in students' chemistry self-efficacy was explained by efficacy-enhancing teaching. Research is being conducted to explore why and how efficacy-enhancing teaching actually causes students to enhance chemistry self-efficacy. My interest is in the mechanisms and mediators. One possible mediator is the type of learning strategies used by students when learning school chemistry. Recently, in a large-scale study of 16,208 Hong Kong Secondary-4 students, my collaborator and I (Cheung & Lai, 2013) found that regular classroom teaching had a direct effect on students' self-efficacy for personal development ($\beta = 0.11$, $t = 12.7$, $p < 0.001$). The study focused on self-efficacy in five domains of personal development: understanding self, understanding others, handling setbacks, stress management, and leisure time management. More importantly, we found that regular classroom teaching directly affected students' use of deep learning strategies ($\beta = 0.39$, $t = 34.7$, $p < 0.001$), which in turn affected their levels of self-efficacy for personal development ($\beta = 0.58$, $t = 50.0$, $p < 0.001$). There are two main types of learning strategies: deep learning strategies and surface strategies (Biggs, Kember, & Leung, 2001). Deep learning strategies can help students understand important information when studying a school subject and include metacognitive control strategies, elaboration strategies, critical thinking, and organization strategies (Lynch, 2006; Marsh, Hau, Artelt, Baumert, & Peschar, 2006). For example, elaboration facilitates students to connect new information with prior knowledge by using strategies such as paraphrasing, summarizing, and creating analogies. Metacognitive control strategies refer to a student's awareness, knowledge, and control of his or her learning. Goal setting, task analysis, and self-testing are examples of metacognitive control strategies. On the contrary, surface learning strategies render students to memorize and reproduce information without understanding. They include strategies such as rehearsal and copying. These strategies do not provide students with the depth of knowledge to understand the relationships between different ideas in a topic. Using a quasi-experimental design, Nbina and Viko (2010) found that students who used metacognitive learning skills tended to have higher levels of chemistry self-efficacy. Therefore, it is likely that the effect of efficacy-enhancing teaching on chemistry self-efficacy shown in Fig. 1 is mediated by the type of learning strategies used by students.

Limitations As with any research, certain limitations were present in my study. Although I used Bandura's (1977, 1997) four sources of self-efficacy information as my theoretical framework for constructing items to measure efficacy-enhancing teaching, the number of items was inadequate to form four separate subscales. Consequently, the differential effects of the four sources of information on students' self-efficacy could not be analyzed. Another limitation in my study is that chemistry achievement was just measured by students' self-reports. Future research should use a better measure of chemistry achievement.

5 Future Research Directions

Self-efficacy is an important affective construct in chemistry education. Chemistry self-efficacy refers to one's beliefs about his or her capability to successfully perform particular chemistry tasks or solve particular chemistry problems. Chemistry students need more than ability, knowledge, and skills to succeed; they also need to have positive self-efficacy beliefs in order to use their knowledge and skills effectively. Although a student did well in his chemistry courses, he may have doubts about his chemistry capabilities and does not feel that he is good enough to choose chemistry major at college. To date, there have been relatively few empirical studies examining chemistry self-efficacy. In this chapter, discussions of previous research on chemistry self-efficacy point to the need for additional efforts in at least three areas.

Firstly, researchers need to refine instruments to measure students' chemistry self-efficacy. It is likely that chemistry self-efficacy is a multidimensional construct. Therefore, attempts should be made by researchers to develop subscales. However, research by Dalgety et al. (2003) indicated that it is difficult to develop a multidimensional scale to measure chemistry self-efficacy; the structure of their 17-item instrument is still unclear because students' responses to the items did not load on the expected factors. The work of Uzuntiryaki and Çapa Aydin (2009) in Turkey showed some promising results from confirmatory factor analysis, but there is a need to test their 21-item college chemistry self-efficacy scale in other contexts.

Secondly, additional studies are required to construct more items to measure the different sources of chemistry self-efficacy. If researchers construct items based on Bandura's (1977, 1997) four sources of information, then four subscales should be developed. Investigations are particularly needed to examine the differential effects of the sources, because the four sources of information may operate differently in different cultures and thus have different effects on self-efficacy (Klassen, 2004). The sources of mathematics self-efficacy have been examined by many researchers (e.g., Lent et al., 1991, 1996; Lopez et al., 1997), and excellent reviews are available (e.g., Usher & Pajares, 2008). When chemistry educators attempt to create more items to measure sources of self-efficacy, they may consider the experiences of mathematics educators. Qualitative research methods such as semi-structured interview are also useful to explore sources of chemistry self-efficacy. Chemistry students may be asked "what sorts of things does your teacher do that help you feel more confident about learning chemistry?" More examples of interview questions are available in Usher (2009).

Thirdly, the common type of research with which chemistry educators are familiar is questionnaire survey administered at one time point. Therefore, not surprisingly, the majority of previous research on students' chemistry self-efficacy was nonintervention research. For example, although the causal relationships among three variables are shown in Fig. 1, causality should be interpreted with caution because my questionnaire survey was cross-sectional in nature. Future research could strive to uncover the causal relationships by using experimental designs. We may investigate how variations in chemistry teachers' levels of implementation of efficacy-enhancing teaching affect students' chemistry self-efficacy and achievement. Readers interested in experimental studies examining self-efficacy are advised to read, for example, Campbell and Hackett (1986), Luzzo et al. (1999), Schmidt and Ford (2003), Schunk (1981), and Schunk and Hanson (1985). Even if questionnaires are used, they can be given to students more than one time a semester or year. In this way, changes in chemistry self-efficacy over time can be monitored.

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Second-Year College Students' Scientific Attitudes and Creative Thinking Ability: Influence of a Problem-Based Learning (PBL) Chemistry Laboratory Course

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Abstract This research examined the effects of a problem-based learning (PBL) chemistry laboratory course for second-year college students ($N = 20$) on students' scientific attitudes with an emphasis on their creative thinking abilities. The findings were contrasted with a traditional laboratory course ($N = 26$) to elucidate any differences in the influence of the courses. Only female students participated in the study which was conducted in a private university for women in Korea. A 20-item *Scientific Attitudes Questionnaire* administered to both groups as a pretest and a posttest revealed that there were significant changes in criticism, cooperativeness, and creativity at the end of instruction only among students in the PBL course. The posttest scores of the *Torrance Tests of Creative Thinking* to gauge students' creative thinking ability were significantly higher for the students in the PBL course on all three dimensions. The research suggests that PBL laboratory courses in chemistry have great potential to positively change students' scientific attitudes towards learning chemistry and enhance their creative thinking abilities.

Keywords Problem-based learning • College chemistry • Laboratory course • Scientific attitudes • Creative thinking ability

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1 Introduction

Practical work in the science laboratory has long been considered an important feature of science education because it provides opportunities for students to not only develop their experimental skills but also to foster positive attitudes towards science. However, according to Hofstein and Lunetta (2004), the potential benefits of laboratory activities have not been exploited to the fullest. When students follow a series of steps in cookbook fashion to conduct an experiment without making connections with what has been learned in class and without providing opportunities for students to make investigations of their own, students tend to become disinterested in science. In most laboratory classes in Korean universities, for example, students passively perform laboratory experiments under the unilateral instruction of their professors (Kim, Yang, & Park, 2006). There is, therefore, a need to change current laboratory practices in Korean universities by providing opportunities for students to develop more positive scientific attitudes and to cultivate creative thinking ability.

Problem-based learning (PBL) implemented in laboratory courses can help students to engage in processes of investigation and inquiry because PBL and inquiry learning are student centered and focus on an active learning environment (Savery, 2006). Problem-solving involves questioning, investigating solutions, sharing and understanding the collected information, and discussing and reflecting upon the findings. Inquiry activities facilitate higher-order thinking abilities, positive attitudes, practical skills, and understanding of nature of science (Lederman & Lederman, 2013). PBL has been also known to be an effective instructional strategy both in cognitive (Dochy, Segers, Van den Bossche, & Gijbels, 2003; Gallagher, Stepien, & Rosenthal, 1992; Hmelo-Silver & Lin, 2000) and affective domains (Dolmans, Wolfhagen, Van der Vleuten, & Wijnen, 2001; Liu, Hsieh, Cho, & Schallert, 2006). However, limited research results have been reported about the effectiveness of PBL on students' scientific attitudes. While PBL is known to be effective in engendering students' creative thinking ability (Delisle, 1997; Tan, 2008), there is limited documentation in the research literature on the assessment of creative thinking ability. To help fill this void, this study was conducted to implement a PBL approach in a chemistry laboratory course involving second-year college students in a Korean university.

2 Theoretical Background

PBL is a learner-centered instructional approach that encourages active participation of students and enables students to acquire essential knowledge and skills through problem-solving processes (Barrows, 1996). In PBL, learning is initiated with an authentic and ill-structured problem that can motivate students (Torp & Sage, 2002). Due to the fact that ill-structured problems have no single answer and various solutions can be generated (Jonassen, 1997), such problems pose a challenge to students who then have to consider all aspects of the problem before arriving at their own solution.

PBL can be designed differently based on context, students, and curriculum (Delisle, 1997; Torp & Sage, 2002). However, all examples follow the same procedure of defining the problem, searching, gathering and sharing information, generating plausible solutions, determining the best-fit solution, and presenting and evaluating the solution. These processes can be implemented both individually and collaboratively (Savin-Baden & Major, 2004). Group discussion is used to define the learning issues in the given problem situation, and individual work is assigned to every student in the group. Subsequently, each student does his/her own assigned work, mainly searching and gathering information required for solving the problem. All the information collected is shared with other students in the group. Then various possible solutions are generated and the best-fit solution is determined based on the shared information through group discussion. Individual and group activities can be performed several times to determine the best-fit solution. After solving the problem, group presentation and evaluation are followed by individual evaluation. In the PBL environment, students have to develop their own learning as active problem solvers and self-regulated learners, set the learning goals, make concrete plans on how to proceed with learning (solve the problem), and collect learning materials and resources needed for problem-solving. At the same time, students are required to share their work and communicate with others in the group.

PBL has been implemented in different learning contexts including science laboratory courses where experimentation can be used as a method for solving problems (Boyce & Singh, 2008; Gallagher, Stepien, Sher, & Workman, 1995; Gürses et al., 2007; Ram, 1999). Different from typical laboratory courses where experimentation is conducted based on a given protocol, students involved in PBL are required to design their own experimentation by ascertaining what they know, what they need to know, and then evaluating or describing the results. In this respect, PBL laboratory courses can be an alternative to typical laboratory courses (Yoon, Woo, Treagust, & Chandrasegaran, 2014). PBL has been shown to produce positive effects in affective areas such as motivation (Albanese & Mitchell, 1993; MacKinnon, 1999), attitudes (Ferreira & Trudel, 2012; Liu et al., 2006), and interests (Dolmans et al., 2001).

The characteristics of a problem itself and constructivist learning environments have been shown to be positively associated with students' motivation, attitudes, and interests (Duch, 2001; Gordon, 1998). Learning in PBL always starts from a problematic situation that is familiar to students and attracts students' interest and raises their curiosity. Active participation of students in learning activities can provide motivation (Pintrich, 2004; Tuan, Chin, & Shieh, 2005) and change students' attitudes. A scientific attitude can be described as a desire to know and understand, a questioning approach to given statements, a tendency to search data and understand the meaning, a demand for verification, and a consideration of consequences (Kind, Jones, & Barmby, 2007). A scientific attitude can also be defined as efforts to engage in inquiry learning, especially in problem-solving, evaluation of ideas and information, and making decisions (Kim, Chung, & Jeong, 1988).

The implementation of PBL has shown positive relationships with changes in scientific attitudes (Kang, 2008; Oh, Kim, & Lee, 2005). Oh et al. (2005) reported that online PBL science classes and PBL science laboratory classes significantly improved students' scientific attitudes. They explained that students acquired positive scientific attitudes while seeking different experimental designs, devising various ways of solving the problems, and deciding on the best solutions. Kang (2008) has suggested that PBL was effective in improving students' scientific attitudes towards engaging in inquiry activities involving real-life situations.

As aspect of scientific attitudes emphasized in this study is creativity which is the ability to produce new, useful, and appropriate products (Boden, 2001). The early definition of creativity was focused on cognitive aspects (Guilford, 1950). Later affective aspects, such as curiosity, voluntariness and motivation, individual characteristics, the environment, and domain-specific knowledge, have been considered as components of creativity (Amabile, 1983; Barron & Harrington, 1981; Maslow, 1968). Among these various components of creativity, creative thinking ability focused more on the cognitive component. The aim of creative thinking ability is not to have the correct answer but rather to pursue the development of varied and unique ideas. Mumford, Mobley, Uhlman, Reiter-Palmon, and Doares (1991) referred to the creative thinking process as a type of problem-solving process. Therefore, creative thinking ability can be defined as the ability that can be developed in the process of problem-solving, especially when students are trying to generate various possibilities, different from the normal, to solve a problem.

During the PBL learning process, students experience higher-order thinking abilities that include critical, creative, as well as logical thinking abilities because more cognitive activities are involved in solving ill-structured problems than structured ones (Choi, 2004). In stating that PBL is effective in enhancing creative and critical thinking abilities, Choi (2001) has specified the kinds of thinking abilities that are required in each step of PBL, namely, originality and fluency, sub-categories of creative thinking ability that are required in defining the problem.

3 Rationale and Research Questions

The main purpose of this study was to investigate the influence of a second-year college students' problem-based learning (PBL) chemistry laboratory course on several affective factors. The influence of the PBL course was compared with a traditional laboratory course for the same duration involving another group of students in the same year. In order to achieve these objectives, the study addressed the following research questions:

1. How does the problem-based learning (PBL) chemistry laboratory course influence students' scientific attitudes in the dimensions of openness, curiosity,

criticism, cooperativeness, voluntariness, persistence, and creativity compared to students in a comparison group who were instructed in the traditional course?
2. How does the PBL chemistry laboratory course influence students' creative thinking abilities in the dimensions of fluency, flexibility, and originality compared to students in the comparison group who were instructed in the traditional course?

4 Methodology

4.1 Research Sample

The research was conducted with 46 students (preservice teachers) in the second year of a 4-year course, majoring in chemistry education at the College of Education in a private university located in Seoul. The students comprised a convenience sample (Merriam, 1998). The treatment group of 20 college students in the chemistry PBL laboratory course was taught by the first author. Another 26 students in the comparison group were involved in a traditional laboratory course. Students in neither group had experienced PBL before. PBL was introduced only for the students in the treatment group, and training sessions were given during the first 2 weeks of the semester. Students were free to choose either of the two laboratory courses. Both groups of students were considered to be equivalent as they had similar college entrance examination scores and general performance average scores based on their end of first year examinations (treatment group mean = 3.69, SD = 0.25; comparison group mean = 3.76, SD = 0.52; $t = 0.44$). In addition, the two groups were considered to have similar chemistry background and laboratory skills because both groups of students had taken same chemistry and chemistry laboratory courses before they enrolled in this laboratory course.

4.2 Research Design

This study used a quasi-experimental design with quantitative data (Anderson, 2000; Creswell, 2003) that used two previously designed questionnaires to solicit information related to several affective factors from second-year college chemistry students who were involved in a problem-based learning (PBL) chemistry laboratory course. In order to make comparisons in particular instances, information was also solicited from a group of students enrolled in a traditional laboratory course that involved carrying out specific laboratory activities based on instructions that were provided. With the small sample size and the likelihood of non-normal distribution, any differences between the treatment and comparison groups and between pre- and posttests were analyzed with nonparametric statistics.

4.3 Description of the Laboratories

Three PBL problems, which were developed to integrate the chemistry topics, laboratory techniques, and analytical methods presented in a typical analytical laboratory course, were given to students in the treatment group for one semester (4 weeks to solve one problem, and 3 weeks to solve two other problems). Laboratory activities were performed by groups of 3–4 students during laboratory sessions held once a week for 3–4 h. Individual groups had a meeting at least once a week in addition to the laboratory class to discuss their experimental design and reflect upon their experimental results, share information, and assign individual work. After the individual group meeting, their solution (experimental design) was discussed with the instructor by either using the university's online message board or in face-to-face meetings. Students then came to the laboratory and proceeded with the experiment as they had planned. After the experiment, they had individual group meetings once more.

Students in the typical laboratory courses performed ten experiments. Prior to a week before the laboratory class, a manual was provided that included "the purpose of experiment," "experimental procedures," and "related theoretical background." Each laboratory session was held 3–4 h once a week. Usually, 3–4 students worked together as a group. Typically, students read the manual and attempted to understand the theoretical background and the experimental procedure before coming to the laboratory. In the laboratory class, the students performed the experiment following the procedure in the manual. Students in each group collected and shared data. After finishing the laboratory activities, they analyzed the data and handed in their final laboratory report. The university's online message board was open for everyone, and students were allowed to come to the instructor's office whenever they needed help.

4.4 Research Instruments

4.4.1 Scientific Attitudes Questionnaire

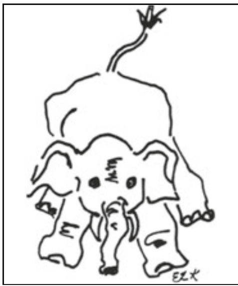
A framework for assessment of the affective domain was developed by Kim et al. (1988) based on previous literature (including Krathwohl, Bloom, & Masia, 1964 and the Ministry of Education and Human Resources Development, 1992) and the assessment framework of the National Assessment of Educational Progress (NAEP). Items developed to assess scientific attitudes were selected for the purpose of this study. Subsequently, a *Scientific Attitudes Questionnaire* consisting of 20 statements was administered to students in both groups as a pretest before the commencement of the laboratory course and again as a posttest at the end of the course. Students' scientific attitudes were assessed in seven dimensions, namely, curiosity, open-mindedness, critical mindedness, cooperation, voluntariness, endurance, and creativity. The complete instrument was developed by Kim et al. (1988) in Korean, and the translated version with a Cronbach's alpha reliability of 0.86 is provided in Appendix. For each statement, students were required to indicate the extent to which they agreed with each statement on a Likert-type scale ranging from "1" for "strongly disagree" to "5" for "strongly agree." Students were given 15 min to complete the questionnaire on each occasion. The overall internal consistency of the questionnaire as measured by the Cronbach's alpha reliability was found to be 0.80 for the pretest and 0.84 for the posttest.

4.4.2 Torrance Tests of Creative Thinking

The *Torrance Tests of Creative Thinking (TTCT)* (Torrance, 1990), is widely used for measuring general creativity when resolving proposed problems; when students are presented with a particular problem in *TTCT*, they would first have to recognize the problem and then analyze the given situation before providing reasons for their hypotheses and predictions. The *TTCT* involves processes that are very similar when resolving problems in science and has been successfully used in gauging creativity of students in middle-school science (Oh et al., 2005) and in high-school science (Suh, 2007).

The *TTCT* was previously translated from English into Korean and then back translated into English by Kim (2004) to ensure that the essence of the instrument had not changed during the translation process. The verbal form of the *TTCT* consists of six exercises relating to each of the tasks, *asking questions*, *guessing causes*, *guessing effects*, *improving products*, *imagining multipurpose*, and *just supposing*. An instructional manual provides information on how each of the tasks is to be performed; details relating to the task of *improving products* are provided in Fig. 1.

The creative thinking ability in each task is based on the three mental characteristics of fluency, flexibility, and originality. These three mental characteristics are defined as follows: (1) fluency is the total number of relevant ideas, (2) flexibility is the number of different categories of relevant ideas, and (3) originality is the number of unusual but relevant ideas. On initial consideration, it may seem that the



This is the stuffed elephant toy that we can easily find in any toy store. It is about 15cm in height and 300g in weight. Think of wise, clever and unique ways to change or transform it to play with more fun. Don't worry about money. Just concentrate on how to make it more fun to play with.

Fig. 1 Instructions in the TTCT manual associated with *improving products* three mental characteristics of fluency, flexibility, and originality in the *TTCT* are not relevant to a chemistry learning environment. However, the nature of PBL enhances the relevance of these mental characteristics because students are required to consider all possible appropriate solutions to a problem before deciding on the most efficient one.

The first author explained what the students were required to do in each of the six tasks according to the instructional manual. Students were then given 40 min to complete the six tasks, first as a pretest before commencing the laboratory course and again 12 weeks later as a posttest on completion of the course. The internal consistency (Cronbach's alpha reliability) of *TTCT* for this study was found to be 0.94.

The scoring of students' creative thinking ability in the six tasks was done by the first and second authors according to the guidelines provided by Kim (2004). The two authors first discussed the scoring instructions until consensus was reached on how best to perform the scoring. Both authors adhered closely to the consensus that they had reached in order to minimize the influence of subjectivity in the scoring, especially with respect to the measure of originality. Answers that are not commonly provided by students were considered to have originality. In particular instances, for example, with respect to "relevant ideas" in fluency, it was left to the discretion of the scorer to decide on the relevance of an answer. The scoring guidelines for each of the three mental characteristics are summarized in Table 1.

Table 1 Guidelines for scoring mental characteristics in the *TTCT* [from Kim (2004)]

Fluency	Flexibility	Originality
1. Decide whether each answer is appropriate or not	1. Categorize the answers that were scored for fluency using the list of categories provided in the manual	1. Examine each answer in the different categories to ascertain whether it is original or not
2. Count the number of appropriate answers	2. Count the number of different categories	2. Score 0 for not original (creative) answer. The list of answers corresponding to score 0 is provided in the manual
3. Answers that you can find out immediately by looking at the picture are considered as inappropriate ones	3. Answers in the same category are counted only once	3. Answers not in the list are scored as having originality
4. Refer to some examples of inappropriate answers provided in the manual		4. Count the number of original (creative) answers

5 Results and Discussion

5.1 *Students' Scientific Attitudes*

In order to address the first research question (How does the problem-based learning (PBL) chemistry laboratory course influence students' attitudes to science learning in the dimensions of openness, curiosity, criticism, cooperativeness, voluntariness, persistence, and creativity compared to students in the comparison group who were instructed in the traditional course?), a nonparametric Mann–Whitney *U* test was conducted to compare the posttest mean rank scores of the two groups for each of the dimensions as well as for the combined instrument.

Although the posttest mean values for the five dimensions as well as for the overall instrument for the treatment group were higher than the corresponding values for the comparison group, these differences were not statistically significant (see Table 2). In addition, the approximate effect size (as categorized by Cohen, 1988) for the difference between the treatment group and the comparison group was relatively small for five of the dimensions, with relatively moderate differences for the remaining two dimensions of voluntariness and persistence.

To further elucidate trends in the mean values, Wilcoxon signed-ranked tests were conducted between the pretest and posttest mean scores for each of the seven dimensions of the two groups as well as for the overall attitudes instrument (see Tables 3 and 4).

In the case of the treatment group, the pretest–posttest mean ranks were statistically significantly different ($p < 0.05$) for four of the seven dimensions—openness, criticism, cooperativeness, and creativity—and the overall instrument. In addition, the approximate effect size (as categorized by Cohen, 1988) of the difference between the posttest and the pretest for the comparison group was small or very small for five dimensions, with relatively average effect sizes for

Table 2 Comparisons of the posttest mean scientific attitude scores between the treatment group ($N = 20$) and the comparison group ($N = 26$) using the Mann–Whitney *U* test

Dimensions	Mean rank: Treatment group	Mean rank: Comparison group	Mann–Whitney *U*	*Z*	Sig.	Effect size
Openness	27.55	20.38	179.00	1.86	0.06	0.34
Curiosity	23.88	23.21	252.50	0.17	0.87	0.49
Criticism	25.73	21.79	215.50	1.01	0.31	0.41
Cooperativeness	27.25	20.62	185.00	1.76	0.08	0.36
Voluntariness	23.40	23.58	258.00	0.05	0.96	0.50
Persistence	21.78	24.83	265.50	0.08	0.94	0.51
Creativity	26.50	21.19	200.00	1.35	0.18	0.38
Overall attitudes	26.80	20.96	194.00	1.46	0.14	0.37

Note: Effect size is calculated based on nonparametric statistics for the two-group independent sample design (Grissom & Kim, 2012)

Table 3 Posttest–pretest mean rank comparisons of the treatment group on the scientific attitude questionnaire using the Wilcoxon signed-ranks test ($N = 20$)

Dimensions	Z	Sig.	Effect size
Openness	2.01	0.04*	0.45
Curiosity	1.02	0.31	0.15
Criticism	2.40	0.02*	0.50
Cooperativeness	2.11	0.04*	0.35
Voluntariness	0.66	0.51	0.05
Persistence	0.93	0.35	0.10
Creativity	2.46	0.14*	0.35
Overall attitudes	2.93	0.00**	0.40

*$p < 0.05$, **$p < 0.01$

Note: Effect size in terms of the PS (probabilistic superiority) value is calculated for the two related samples design (Grissom & Kim, 2012)

Table 4 Posttest–pretest mean rank comparisons of the comparison group on the scientific attitudes questionnaire using the Wilcoxon signed-ranks test ($N = 26$)

Dimensions	Z	Sig.	Effect size
Openness	2.15	0.32*	0.35
Curiosity	0.30	0.77	0.12
Criticism	0.27	0.79	0.00
Cooperativeness	0.57	0.57	0.15
Voluntariness	0.44	0.66	0.12
Persistence	0.29	0.77	0.12
Creativity	0.61	0.54	0.15
Overall attitudes	0.97	0.33	0.23

*$p < 0.05$

Note: Effect size in terms of the PS (probabilistic superiority) value is calculated for the two related samples design (Grissom & Kim, 2012)

the openness and criticism dimensions. However, for the comparison group, the pretest–posttest mean ranks were statistically significantly different ($p < 0.05$) for only the openness dimension. The difference for the overall instrument was not statistically significant. At the same time, the approximate effect size (as categorized by Cohen, 1988) of the difference between the posttest and the pretest for the comparison group was small or very small for all seven dimensions.

In other studies with Korean students, differences in the effectiveness of changes in scientific attitudes were noted to be dependent on the participants and the course design. For example, Shin and Lee (2011) reported that overall scientific attitudes had changed significantly after the PBL-based astronomical observation program with elementary science-gifted students, especially in the dimension of openness and voluntariness but not in curiosity and criticism. According to Kim and Lee (2011), after the implementation of PBL with early childhood preservice teachers, the overall scientific attitudes had changed significantly. In the study discussed in this chapter, PBL was implemented in a laboratory course for second-year college students. Inquiry processes, especially thinking of various methods to solve problems and selecting the best one, were emphasized throughout the entire course.

5.2 *Students' Creative Thinking Abilities*

Comparisons were first made between the posttest scores of the two groups of students' creative thinking abilities in the three dimensions of the *TTCT* (fluency, flexibility, and originality) as well as on the overall *TTCT* scores using the Mann–Whitney *U* test analysis procedure. This analysis was performed in response to the second research question (How does the PBL chemistry laboratory course influence students' creative thinking abilities in the dimensions of fluency, flexibility, and originality compared to students in the comparison group who were instructed in the traditional course?). The results of the analysis indicate that the differences between the mean scores of the three dimensions of the *TTCT* as well as for the overall instrument were statistically significant in favor of the treatment group (see Table 5). At the same time, the approximate effect size (as categorized by Cohen, 1988) of the difference between the treatment group and the comparison was relatively small for all the three dimensions as well as for the whole instrument.

The Wilcoxon signed-rank tests were next conducted to compare the differences between the pretest and posttest rank mean scores for each of the three dimensions for the treatment and comparison groups as well as for the overall attitudes instrument (see Tables 6 and 7).

Table 5 Comparisons of the posttest mean *TTCT* scores in the three dimensions between the treatment group ($N = 20$) and the comparison group ($N = 26$) using the Mann–Whitney *U* test

Dimensions	Mean rank		Mann–Whitney *U*	*Z*	Sig.	Effect size
	Treatment group	Comparison group				
Fluency	28.05	20.00	169.00	−2.02	0.04*	0.33
Flexibility	30.73	17.94	115.50	−3.21	0.00**	0.22
Originality	31.75	17.15	95.50	−3.66	0.00**	0.18
Overall *TTCT*	30.75	17.92	115.00	−3.21	0.00**	0.22

*$p < 0.05$, **$p < 0.01$

Note: Effect size is calculated based on nonparametric statistics for the two-group independent samples design (Grissom & Kim, 2012)

Table 6 Posttest–pretest mean rank comparisons of the treatment group on the three dimensions of the TTCT using the Wilcoxon signed-ranks test ($N = 20$)

Dimensions	*Z*	Sig.	Effect size
Fluency	−3.87	0.00**	0.93
Flexibility	−3.73	0.00**	0.90
Originality	−3.52	0.00**	0.90
Overall TTCT	−3.85	0.00**	0.93

**$p < 0.01$

Note: Effect size in terms of the PS (probabilistic superiority) value is calculated for the two related samples design (Grissom & Kim, 2012)

Table 7 Posttest–pretest mean rank comparisons of the comparison group on the three dimensions of the TTCT using the Wilcoxon signed-ranks test ($N = 26$)

Dimensions	*Z*	Sig.	Effect size
Fluency	−1.47	0.14	0.19
Flexibility	−0.20	0.84	0.04
Originality	−2.08	0.04*	0.46
Overall TTCT	−0.45	0.66	0.23

*$p < 0.05$

Note: Effect size in terms of the PS (probabilistic superiority) value is calculated for the two related samples design (Grissom & Kim, 2012)

The treatment group comparisons were statistically significantly different ($p < 0.01$) for all three dimensions of students' creative thinking abilities, while the approximate effect size (as categorized by Cohen, 1988) of the difference between the posttest and the pretest was very large for all three dimensions as well as for the whole instrument. However, there was a statistically significant difference ($p < 0.05$) only for the originality dimension of the comparison group (see Table 7). The approximate effect size (as categorized by Cohen, 1988) of the posttest–pretest difference for all the three dimensions and the overall instrument was relatively small or very small.

Creativity was measured by students forming new ideas or hypotheses, testing and developing these hypotheses, and transmitting the data (Dass, 2004). A distinct relationship between creativity and scientific attitudes has not been clearly reported previously; however, there are some PBL studies which reported the effectiveness in both creativity and scientific attitudes (Cho, Kim, & Lee, 2011; Yoon & Woo, 2009). The nature of creativity in science has some characteristics similar to creativity involved in scientific attitudes. In that sense, the effectiveness in creativity after PBL is consistent with the effectiveness in scientific attitudes.

6 Conclusions and Implications for Teaching and Research

This study has shown that although the mean rank values for all seven dimensions of the *Scientific Attitudes Questionnaire* were not statistically different for the treatment group compared to the comparison group. However, comparison of the pretest and posttest mean rank scores for the treatment group showed that there was a statistically significant improvement for the openness, criticism, cooperativeness, and creativity dimensions as well as for the overall scientific attitudes instrument. As for the comparison group, the pretest–posttest comparison was statistically significant for only the openness dimension. Examining in more detail, the creativity dimension showed that the PBL laboratory course had a significant influence on students' creative thinking abilities with statistically significantly differences in the mean rank scores of the fluency, flexibility, and originality dimensions of the *TTCT* as well as on the overall mean of the *TTCT*. As for the comparison group, the pretest–posttest difference was statistically significant for only the originality dimension, but there was a decrease in originality.

The above findings suggest that PBL laboratory courses in chemistry have a great potential to positively change students' scientific attitudes towards learning chemistry and enhancing their creative thinking abilities. This approach to chemistry laboratory courses is in contrast to the traditional laboratory programs that require students to follow instructions in laboratory manuals in a cookbook manner with the aim of confirming predetermined results. Students in this PBL course were able to identify the problem, consider plausible solutions to solve the problem, select appropriate solutions and design their own experiments, and reflect upon the results. All these activities require creativity in science and criticism of one's own thinking.

There are two limitations of this study. The first limitation was the sample size with two small classes in a Korean university for female students. Nevertheless, the fact that students in the treatment and comparison groups, who had similar chemistry backgrounds in content knowledge and practical skills, leads us to believe that the results of this study are valid and reliable. The research findings do demonstrate important positive affective outcomes when implementing laboratory work using problem-based learning. However, there is need to extend research of a similar nature to include PBL chemistry laboratories in more institutions in varying contexts, both in high schools and in universities, with different samples consisting of male only or female and male students in order to further confirm, or refute, the viability of conducting similar programs. The second limitation concerns the scoring of the *TTCT* which may have been biased even though it was done step-by-step following the manual. However, the relatively high-reliability value of this instrument in the study is consistent with other studies.

Appendix: Scientific Attitudes Test

Directions to students: Please circle your most appropriate response to each statement

No.	Statements	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
1	I carefully listen to other group members' opinions even though their opinions are different from mine	1	2	3	4	5
2	After an experiment, I put the apparatus back with other members	1	2	3	4	5
3	I prefer to watch what other members do during an experiment rather than do it myself	1	2	3	4	5
4	I would like to know the reason whenever I see a new phenomenon	1	2	3	4	5

(continued)

No.	Statements	Strongly disagree	Disagree	Not sure	Agree	Strongly agree
5	I usually examine the experimental results whether or not they are reasonable enough	1	2	3	4	5
6	I look for the things that I can do and voluntarily do them	1	2	3	4	5
7	I repeat an experiment without disappointment if the experimental result is different from what I expected	1	2	3	4	5
8	I am directing my efforts to invent new things	1	2	3	4	5
9	I am always curious about the reason why it is not working whenever I see something broken	1	2	3	4	5
10	I can modify (change) my opinion through discussion with other members who have different opinion from me	1	2	3	4	5
11	I always ask questions whenever I think the teacher's explanation is incorrect	1	2	3	4	5
12	I feel I would like to help other members when they are not good at using some apparatus	1	2	3	4	5
13	Whenever I come across scientific problems, I search reference books and voluntarily try to solve the problems	1	2	3	4	5
14	During an experiment, I quit if the experimental procedure becomes complicated	1	2	3	4	5
15	I try to find a new (different) way to solve problems	1	2	3	4	5
16	I frequently ask questions like "what," "how," "when," and "why"	1	2	3	4	5
17	I feel shy when my opinion is wrong	1	2	3	4	5
18	Even though others say something is correct, I propose a different opinion if the evidence is not good enough	1	2	3	4	5
19	Even though others have completed doing an experiment, I continue to do my own experiment	1	2	3	4	5
20	I try to improvise inconveniences when I use scientific apparatus	1	2	3	4	5

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Neuroscience Engagement: The Influences of Chemistry Education on Affective Dimensions

Chia-Ju Liu and Chin-Fei Huang

Abstract Chemistry education is the combination of chemistry learning and teaching. The most important issues in chemistry education include understanding how students learn and how teachers teach chemistry. Although many studies have indicated that addressing cognitive dimensions could promote students' chemistry learning achievements, to improve the whole efficacy of chemistry education, the affective dimensions must be integrated into the consideration of students' learning and teachers' teaching. The difficulties of measuring the affective dimensions have been solved by using neuroscience technologies. In this chapter, the authors review the use of neuroscience technologies on measuring the affective dimensions and then introduce the influences of chemistry learning on the affective dimensions. Furthermore, the combination of chemistry education and fundamental findings of cognitive neuroscience, such as electroencephalogram (EEG), event-related potentials (ERPs), and functional magnetic resonance imaging (fMRI), is illustrated in this chapter to provide specific and objective suggestions to chemistry learners, educators, and curriculum designers.

Keywords Affective dimension • Chemistry education • Neuroscience

1 Introduction

Chemistry is an important branch of science, which involves the elements, properties, and interactions of substances. The identification of chemistry reveals that this subject plays a critical role in explaining the natural world. However, the complexity of the content of chemistry, such as its abstract concepts or submicro representations (atoms or molecules), makes it difficult for students to learn (Gilbert & Treagust, 2009; Huang & Liu, 2012).

To assist students in their chemistry learning, the cognitive and affective dimensions of learning should be considered together. The cognitive dimensions of chemistry learning are related to students' background knowledge, their abilities

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of reorganization and memory, their understanding of the content knowledge of chemistry, or their operation of the representations of chemical structural formulas. In contrast, the affective dimensions of chemistry learning focus on students' learning emotions. Although the cognitive dimension of chemistry learning could help students' understanding while learning chemistry, the affective dimension can decide their intentional learning and learning directions. In other words, the affective aspect guides what contents of chemistry students choose to learn and how they learn them. Before students learn chemistry, therefore, these affective dimensions need to be clarified.

Both cognitive and affective dimensions of chemistry learning are difficult to assess by only using questionnaires or interviews. With regard to the cognitive dimension, past studies have indicated that many cognitive processes are difficult to explain verbally, such as mental rotation or memory, and these studies suggest that a good way to explore human cognitive processing is to use neuroscience methodologies (Bragh & Ferguson, 2000; Huang & Liu, 2012; Liu et al., 2013a). Why is it worth investigating humans' cognitive processing using such methodologies? Spitzer (2012) suggests some important reasons. He argues that "to understand learning is to understand the brain" (p. 1) and indicates that neuroscience is just the beginning step in uncovering the complex cognitive processing of attention, perception, emotion, evaluation, and actions. He also addresses an interesting metaphor—that "brain-based learning" is a phrase as meaningful as "leg-based running." It is a very interesting and important comment. We need to understand clearly how the brain thinks because human thinking is based on the work of the brain. Thus, it is reasonable and essential to understand the cognitive dimension via the use of neuroscience methodologies.

In terms of the affective dimension, in previous studies affective feedback has generally been collected from students' self-reports, but those responses are more subjective than biological evidence. Therefore, some studies have suggested that research on affective processes must combine neuroscience methodologies such as electroencephalograms (EEG), event-related potentials (ERPs), and functional magnetic resonance imaging (fMRI), combined with questionnaires and interviews (Huang & Liu, 2012; Liu et al., 2013a; Wang, Chiew, & Zhong, 2010). However, compared to the cognitive dimension, the affective dimension is less often discussed in chemistry learning. Therefore, in this chapter, we investigate how the learning of chemistry can be improved through an understanding of the affective dimension by engaging neuroscience methodologies and then conclude with further implications for teaching.

2 The Affective Dimension and Its Importance in Chemistry Learning

Learning new knowledge is one of the most important and complex cognitive processes for humans, as a human's willingness to learn new knowledge is the key point before starting to learn (Ferdenzi et al., 2011), including their motivation and self-efficacy (McInerney & van Etten, 2004). A person's willingness to learn is guided by the affective dimension, which is defined as emotions in this chapter.

The categories of emotions, such as positive and negative emotions, have received an increasing amount of attention in recent years. Caine and Caine (1994) mentioned that what people learn is influenced and organized by emotions which are based on expectancy, and which have an important connection to memory. Ferdenzi et al. (2011) also mentioned that affection can be defined as a mental state that is characterized by emotional feeling. Hence, emotions must be an essential aspect of the affective dimension in chemistry learning. Further, the emotions could promote a person's willingness and motivation to learn.

The emotions of chemistry learning are affected by learners' life experiences. The combination of chemistry knowledge from textbooks and life experiences represents students' affect in chemistry learning. For example, the experiment of the manufacture of soap is an important chapter in organic chemistry, which usually attracts female students' interest and positive emotions. In contrast, the explosion which occurs when sodium is dissolved in water usually attracts male students' interest and positive emotions. In this chapter, firstly, we discuss the influences of science learning on the affective dimensions, and then focus on the specific subject—chemistry learning.

These examples show that the affective dimension is important in chemistry learning. The more positive emotions that are induced, the more interested and focused is the chemistry learning that occurs.

3 Limitations of Studies Exploring the Affective Dimension

The affective dimension in chemistry learning focuses on emotions which can be separated into positive and negative emotions (Moridis & Economides, 2008). Most assessments of the affective dimension in previous studies were based on students' self-reporting via questionnaires and interviews. For example, the State-Trait Anxiety Inventory (STAI) (Spielberger, 2005) is a questionnaire which has often been used to assess students' negative emotions. This self-report inventory includes 20 items. Responses to the items range from 1 to 4, as follows: (1) not at all, (2) somewhat, (3) moderately so, and (4) very much, according to the students' feelings. The range of scores is from a minimum of 20 (highest anxiety) to a maximum of 80 (lowest anxiety). Through this kind of questionnaire, the learners' negative emotions, such as anxiety, are assessed. Although questionnaires regarding the assessment of the affective dimension such as STAI always have high reliability and validity, self-reporting has been argued to be a subjective methodology. In recent years, many studies have suggested that researchers should investigate the affective dimension of learning by engaging neuroscience methodologies since the data from such methodologies are widely regarded as providing highly objective evidence (Huang & Liu, 2012; Liu et al., 2013a; Wang et al., 2010).

4 Neuroscience Technologies as Assessment Tools for the Affective Dimension

Three kinds of neuroscience technologies are most commonly adopted in exploring students' learning. First is the electroencephalogram (EEG). EEG is a procedure to measure the electrical activity of the brain through the skull and scalp (Coles & Rugg, 1995). The participants need to wear an electrode cap (commercial electrocap, Electro-Cap International, Eaton, OH) on their head before performing a set task (Fig. 1).

When students recognize or apply specific affective reflections, the corresponding electrical activities in the brain (EEG raw data) are induced (Fig. 2).

Figure 2 shows the EEG data when the participants recognize or apply specific cognitive processing. As has already been mentioned, EEG data is a procedure for measuring the electrical activity of the brain through the skull and scalp (Coles & Rugg, 1995). The HEOR (horizontal electrooculogram right) and HEOL (horizontal electrooculogram left) data indicate the horizontal electrooculogram (EOG), and the VEOU (vertical electrooculogram up) and VEOL (vertical electrooculogram low) data record the vertical EOG. The reason why recording of these four electrodes is necessary is because the participants must pull and drag the muscles

Fig. 1 A participant wearing an electrode cap

Fig. 2 Example of EEG raw data

around the eyes when they read the tasks on the computer screen or when they blink. Hence, the HEOR, HEOL, VEOU, and VEOL would be the adjustment data to remove the artifact data which occurs as a result of blinking or muscle vibration, to correct the EEG raw data. The other EEG raw data shown as serial symbols and numbers in Fig. 2, such as C3, CZ, and C4, correspond with the different brain areas shown in Fig. 3.

In Fig. 3, there are assigned symbols and numbers in each EEG signal, which indicate the electrode site in the electrode cap. These symbols and numbers follow the 10–20 international systems, where the symbols indicate the brain area and the numbers reflect whether the induced EEG signals are in the left or the right brain hemisphere. For example, the symbol "F" is located in the frontal lobe of the brain area, the odd numbers (1, 3, 5, 7) are located in the left brain hemisphere, and the even numbers (2, 4, 6, 8) are located in the right brain hemisphere.

After collecting the EEG raw data, the parameters of the EEG data analysis need to be set, such as the frequency ranges of the filter, the electrical resistance of

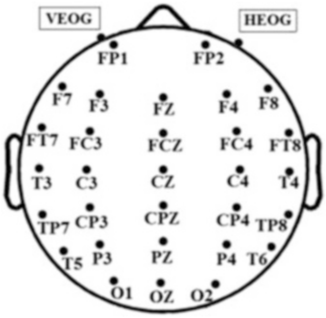

Fig. 3 The electrode sites of the electrode cap

electrode impedance, or the criteria of the baseline. The explanations of the analyzed EEG data need to consider different brain areas and hemispheres.

Aftanas and Pavlov (2005) mentioned that some reflection of the affective dimension such as negative emotions could be reflected in posterior brain areas by using EEG analysis. Dimensional complexity of EEG activity over the frontal cortical regions has also been found during affective imagery (Aftanas et al., 1998; Ray, Moraga, Lutzenberger, Elbert, & Birbaumer, 1993). In Fig. 4, Aftanas et al. (1998) analyzed different affective responses on different power values of the brain map from the EEG data. Power values give an indication of the degree of brain activity. In their study, Aftanas et al. (1998) found that the different affective responses induce different activities in the theta, alpha 1, alpha 2, and beta frequency bands individually in different brain areas (Fig. 4).

In Fig. 4, "NEUT" means that the participants in the study were experiencing neutral emotions, "NEG" indicates that they were experiencing negative emotions, while "POS" indicates that they were experiencing positive emotions. The black color in the brain map of Fig. 4 illustrates higher power values, while the light gray color indicates lower values. There are four power values from different frequency bands which include the theta, alpha 1, alpha 2, and beta frequencies illustrated in the research of Aftanas et al. (1998). The results of their research provide evidence that the EEG power values of different brain maps could indicate different human emotions.

The second kind of neuroscience research methodology used to assess affect is event-related potentials (ERPs). ERPs are collected when participants respond to an assigned task. The raw data (EEG) of ERPs focus on a specific cognitive or affective response which is from the electrical activity of the brain. Take the ability of mental rotation as an example; when participants take part in an ERP experiment about mental rotation, the contents of the task must induce their abilities of mental rotation. The control task needs to be designed in the ERP experiment to confirm that the participants really use mental rotation to do the mental rotation experimental task. After collecting the ERP raw data, the signals need to be amplified using SynAmps/SCAN 4.4 hardware and software (NeuroScan, Inc., Herndon, VA). The noise signals need to be filtered out automatically, and the frequency ranges of the filter, the electrical resistance of the electrode impedance, and the criteria of the

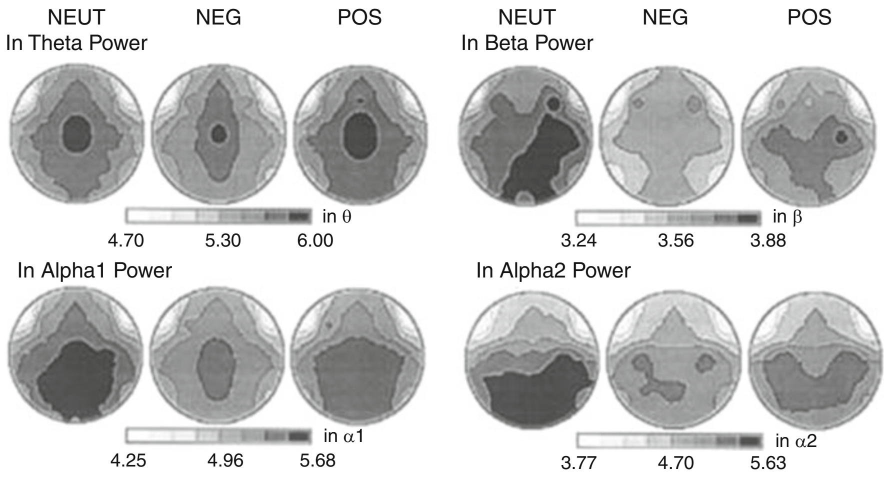

Fig. 4 Brain map from EEG data in different frequency bands (Aftanas et al., 1998)

baseline also all need to be set correctly. Then, the researchers need to find out the meaningful segments of EEG data and integrate and average them into the ERP waveform (Huang & Liu, 2013).

In Fig. 5, there are many coding numbers which indicate the individual ERP components from the ERP waveform, such as P1, N1, P2, N2, and P3. These different ERP components could reflect the different specific types of cognitive processing. For example, the P3 component could reflect participants' attention. Ho et al. (2012) used the P3 component to explore the age-related changes of task-specific brain activity in normal aging. They found that younger adults showed higher amplitude of the P3 component than elderly adults, proving that human attention decreases with age.

In the last paragraph, the code "N" means negative brain potentials in the brain wave data, while the code "P" indicates positive potentials in the brain wave data. The components of brain waves such as P1, N1, P2, N2, and P3 have been defined in previous neuroscience studies. In a similar case, the analyzed ERP waveform could reflect that when the participants respond to a task about mental rotation, a specific component, which is called rotation-related negativity, is induced with latency between 400 and 800 ms (Heil & Rolke, 2002; Huang & Liu, 2012) (Fig. 6).

Kiefer, Schuch, Schenck, and Fiedler (2007) discussed affect and memory using ERPs. The results of their study revealed that the neurocognitive mechanisms during encoding subserving later successful recall depend on the affective state. In their study, the ERP data were transferred into the data of the brain map (Fig. 7). The left data of the brain map in Fig. 7 show the state of brain activity when participants were experiencing positive affect (i.e., they were in a good mood), while the right data of the brain map in Fig. 7 shows the state of brain activity when the participants were experiencing negative affect (i.e., they were in a bad mood). These two different sets of brain map data show that when participants exhibit

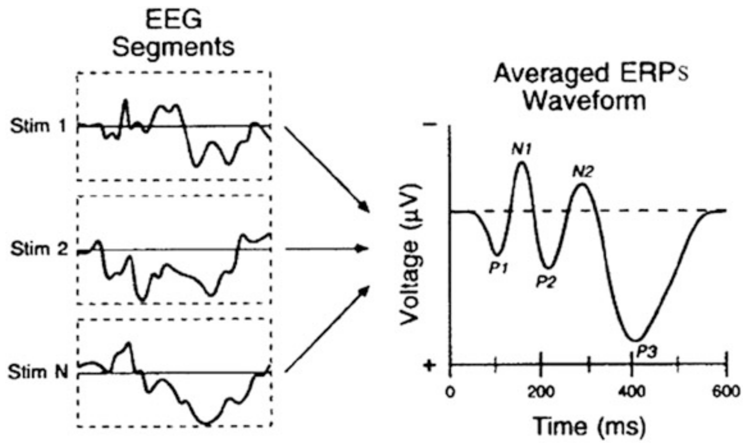

Fig. 5 The average ERP waveform from the EEG segments

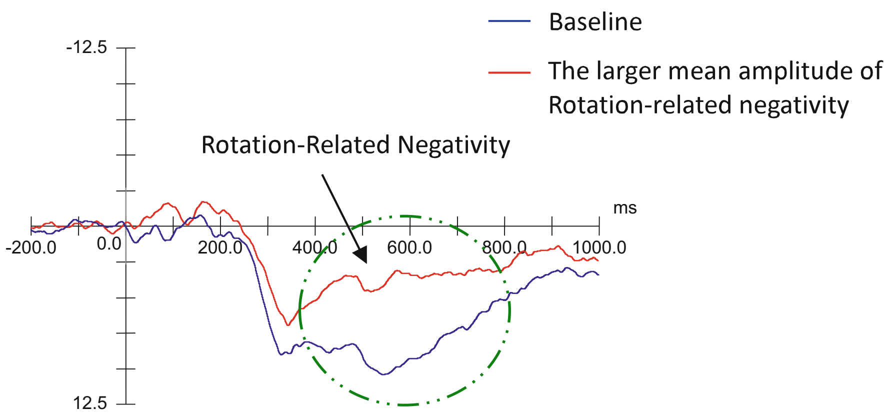

Fig. 6 The rotation-related negativity in ERP analysis (Huang & Liu, 2012)

positive affect, the parietal lobe of the brain is more active. In contrast, the participants' frontal lobe of the brain is more active when they experience negative affect. The results provided important evidence of the areas of the brain that are affected when participants experience particular affects.

In addition, the third kind of neuroscience technology to assess affect is functional magnetic resonance imaging (fMRI) (Fig. 8). Many previous studies have investigated humans' affective responses by using fMRI (Compton & Banich, 2003; Goldin, McRae, Ramel, & Gross, 2008).

Take the study of Goldin et al. (2008) as an example; their study asked participants to watch some unique file clips which were chosen by the authors and to think about their feelings in the fMRI situation (Fig. 9). These clips were defined as

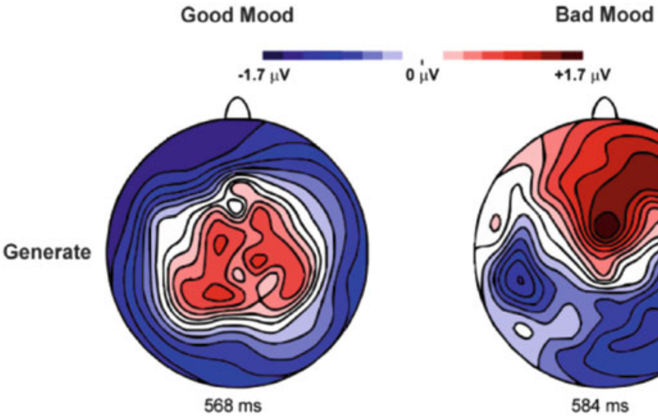

Fig. 7 The different brain topographies for positive emotion (good mood) and negative emotion (bad mood) (Kiefer et al., 2007)

Fig. 8 Functional magnetic resonance imaging (fMRI)

neutral or negative, meaning that they could induce the participants' neutral or negative emotions.

The common fMRI data are like that shown in Fig. 10 (Compton & Banich, 2003) and aim to reveal the explicit brain area that is stimulated when participants are shown pictures designed to induce different affective responses. In Fig. 10, the baseline of the fMRI data is the brain activity when the participants are shown the

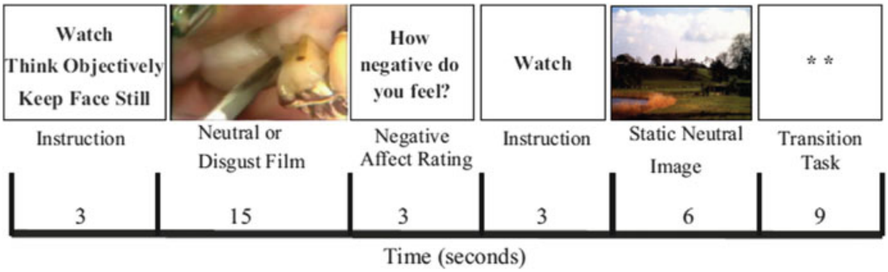

Fig. 9 The experimental design and neutral or disgusting film for affect in fMRI (Goldin et al., 2008)

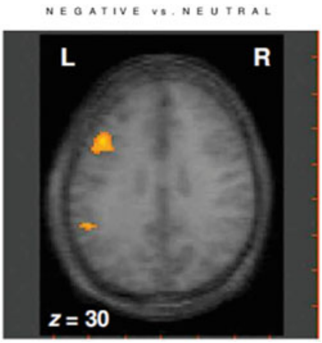

Fig. 10 The different affective reflections in fMRI data (Compton & Banich, 2003)

neutral material. However, when they are shown the negative material, higher brain activity is shown in the left brain hemisphere compared with the baseline (Fig. 10).

The affective dimension is the initial motivation in learning. Students' affective responses in chemistry learning guide them to choose what they want to learn and how they learn it. Thus, exploring the affective dimension in chemistry learning is very important. Until now, most researchers have investigated affect through students' self-report questionnaires and interviews. This chapter introduces three important and commonly used neuroscience methods, EEG, ERPs, and fMRI, as assessment tools of the affective dimension.

In this chapter, the authors take the studies of Aftanas et al. (1998), Compton and Banich (2003), Kiefer et al. (2007), Goldin et al. (2008), and Huang and Liu (2012) as examples to verify that the neuroscience methodology could successfully provide important scientific evidence to prove the role of mental cognitive and affective processing in social learning. We believe that the combination of neuroscience methodologies with questionnaires and interviews is likely to become a trend in future research.

In the past few years, some researchers have adopted neuroscience methodologies to investigate the influences of affect on learning. In the following sections, the authors introduce some of this research. The first study is about affect, attention, and scientific creativity, while the second focuses on gender differences in affective reflections in computer-based learning and assessment.

5 Affect, Attention, and Scientific Creativity in Chemistry Learning

Lubart and Getz (1997) mentioned that emotion is a very important factor affecting scientific creativity. Scientific creativity, which is defined as a logical problem solving process, is an important element in chemistry learning. Humans always solve problems of daily life by using their background knowledge, but they need to solve problems about new or specific situations by using divergent thinking which is based on their background knowledge or life experiences. Scientific creativity not only plays an important role in daily life but it is also specifically critical in solving chemical problems.

Besides background knowledge and divergent thinking, affect is also an important factor influencing scientific creativity. However, there are some conflicting findings in the previous studies. George and Zhou (2002) indicated that negative emotions improve the skills involved in scientific creativity, while positive emotions restrain such creativity. On the other hand, Petty and Cacioppo (1986) found that positive emotions improve a person’s scientific creativity. Recently, Filipowicz (2006) proposed that positive emotions raise the performance of scientific creativity in some cases and restrain it in others. To clarify this issue, Huang, Shen, and Liu (2008) used the EEG methodology to ensure that the participants’ emotions were really being induced while analyzing their scientific creativity in chemistry learning. In their project, they chose 30 pictures from the International Affective Pictures System (IAPS) to induce the participants’ affect. Of these pictures, ten showed positive emotions, ten showed negative emotions, and ten were neutral in not reflecting any emotion. Figure 11 shows examples of these pictures.

All participants needed to take part in the three affect experiments while wearing an electrode cap to collect the EEG data. At first, the participants would see a red cross in the center of a computer screen, which was used to arouse their attention. Then they were asked to complete tasks A, B, and C, randomly selected to induce the corresponding emotions. For example, if a participant was asked to complete task A, his/her positive response would be induced by looking at the positive affect pictures. After completing the task A affect experiment, he/she was asked to answer questionnaire A on scientific creativity which combines chemistry background knowledge. For example, one question of the scientific creativity questionnaire is as follows:

> What could iron make? Please think of products with the physical and chemical characteristics of iron.

Then, this participant was asked to complete task B and scientific creativity questionnaire B two hours later. Finally, the participant was asked to complete task

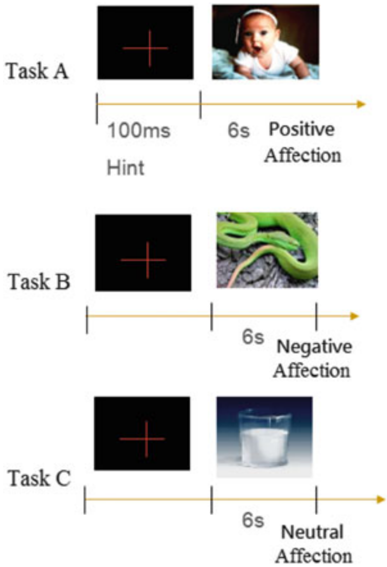

Fig. 11 Example of pictures from IAPS and the series of stimuli (Huang et al., 2008)

C and scientific creativity questionnaire C 2 h after that (the tasks and questionnaires are shown in Huang et al., 2008).

There are two parts to the EEG analysis in Huang, et al.'s research (2008). At first, the researchers analyzed the EEG data to make sure that the participants' emotional responses really were induced. The EEG data from task C (neutral affect) was the baseline of the EEG waveform for individual participants. If the participants showed more positive than neutral affect, the power value of the alpha frequency band would be higher. In contrast, if the participants showed more negative than neutral affect, the power value of the alpha frequency band would be lower (Huang et al., 2008). The data which did not reflect the expected emotions were rejected. Second, the data which were accepted were analyzed to identify changes in the power value of the theta frequency band. The theta frequency band is always identified as the indicator to assess creativity.

The results of the research by Huang et al. (2008) showed that, compared to the natural emotions, scientific creativity is improved with both positive and negative emotions. Furthermore, the performance of scientific creativity is better with negative than with positive affect. The most important contribution of their research is that they used EEG data to ensure that the participants were really inducing the assigned affect before administering the scientific creativity questionnaires. An example of the EEG data is shown in Fig. 12.

Figure 12 shows an example of EEG data with neutral and positive affective reflection. The left figures indicate the brain activity of natural affect, while the right figures show the brain activity of positive affect. The criterion of inducing positive affect is brain activity in the theta band of the frontal lobe.

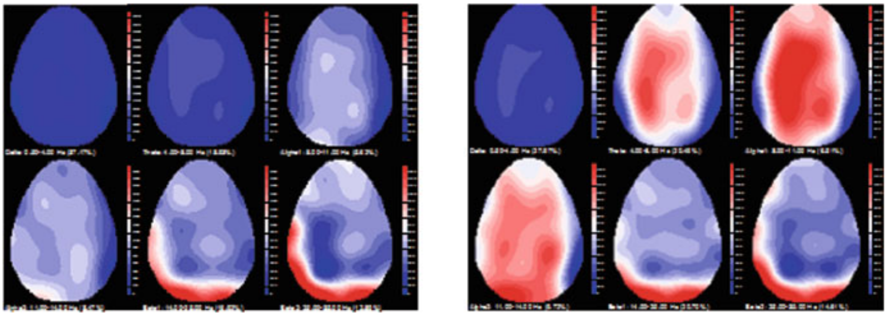

Fig. 12 An example of EEG data with emotional reflection: (**a**) *left figures*: neutral emotion; (**b**) *right figures*: positive emotion (Huang et al., 2008). Note. The *red area* means higher activity of the brain wave, and the *blue area* means lower activity of the brain wave

Besides the effect of affect, attention has been focused on another factor influencing scientific creativity in chemistry learning. A case study from Liu et al. (2012) indicated the influence of the 40 Hz frequency band, which is induced by the EEG on attention processing. They analyzed four stages of EEG data from each participant. In the first stage, the participants were asked to take a rest and close their eyes. In the second stage, they were asked to listen to some classical music with their eyes closed. In the third stage, the participants were asked to take a rest and close their eyes again. In the fourth stage, they were asked to listen to some popular music with their eyes closed.

Their study hypothesized that higher attention is related to higher positive affect. The study applied phase synchrony analysis and bi-coherence analyses (ρ) to explore the students' attention processing (Figs. 13 and 14). A higher ρ indicated that the participants paid more attention in that stage. In Fig. 13, the result showed that the music in stages II and IV promoted the participants' attention more than in stages I and III. This finding means that both classical music and popular music could promote the participants' attention compared with the resting state.

Basically, the findings in Fig. 13 are not really surprising to us. But, there is a very interesting phenomenon in this figure. The authors found that, in general, the participants show attention loss between stages II and III. In other words, these participants aroused their attention quickly by listening to classical music and then lost attention quickly when the music stopped. Could human attention change so fast? Or is this a special situation? To clarify this finding, we analyzed the four stages using bi-coherence analysis (Liu et al., 2013b).

This study also uses bi-coherence as the instrument to analyze data. In clinical practice, it is applied to analyze useful information and determine the use of anesthetic neuroactive drugs for nerve fibers by observing EEG changes in cerebral functions [9]. The bi-coherence of two signals, $x(t)$ and $y(t)$, is defined by (Nikias and Petropulu 1993):

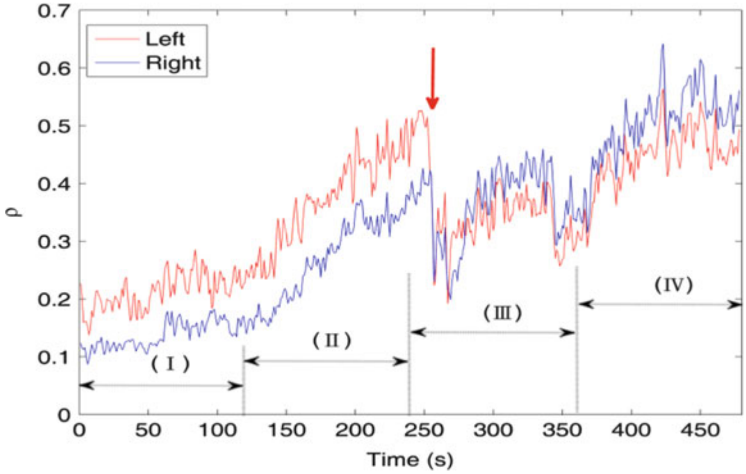

Fig. 13 The EEG data of the *left* and *right* brain hemispheres from four experimental stages (Liu et al., 2012). Note. The *red line* represents brain wave activity in the *left brain* hemisphere; the *blue line* represents brain wave activity in the *right brain* hemisphere

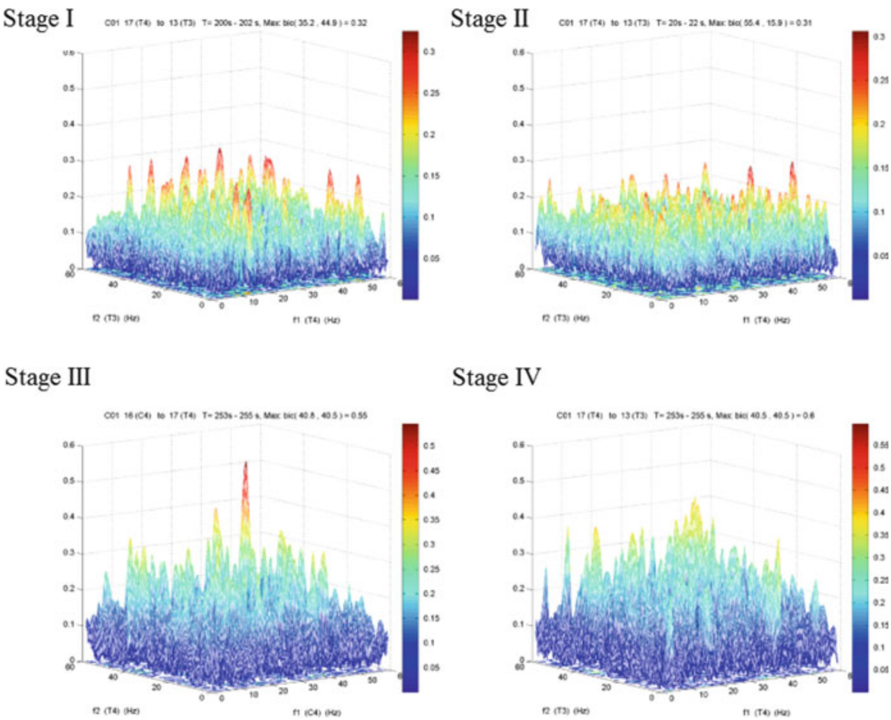

Fig. 14 The data of bi-coherence from stage I, stage II, stage III, and stage IV. (Modified from Liu et al., 2012)

$$B(f_1, f_2) = E[X(f_1)Y(f_2)X^*(f_1 + f_2)]$$

where $X(.)$and $Y(.)$ are complex values calculated by using Fourier transforms. $X^*(.)$ is the complex conjugate of $X(.)$, and $X(f_1) \cdot Y(f_2) \cdot X^*(f_1 + f_2)$ is the triple product, which is the accumulation value obtained from bi-coherence analysis, and E is the expected value. Bi-coherence is defined as the degree of phase coupling after normalization. The bi-coherence value was calculated by the defined formula:

$$\mathrm{BIC}(f_1, f_2) = \frac{B(f_1, f_2)}{P_{xx}(f_1)P_{yy}(f_2)P_{xx}(f_1 + f_2)}$$

where BIC is the strength of phase coupling of the two signals at a specific frequency; and $P_{xx}(f_1)$ and $P_{yy}(f_2)$ are the power spectral density of $X(.)$ and $Y(.)$. The BIC values fall into the range of [0 1].

The results of the bi-coherence analysis showed that the whole brain phase synchronization occurs at the 40 Hz frequency bands and lasts about 400 ms in the EEG data and seems to play an important role in inducing auditory attention loss (Fig. 14). We suggest that human attention could be induced very quickly and could last for a period of time. However, when the brain pays attention for a long time, it needs to take a rest. We suppose that the 40 Hz would be an indicator displaying the highest attention, which a human could pay. In other words, human attention loss will occur with the appearance of 40 Hz.

The specific finding of 40 Hz in the study of Liu et al. is supported by other studies. Lutz, Greischar, Rawlings, Ricard, and Davidson (2004) also mentioned that meditation would induce higher synchronization of 40 Hz in the whole brain, which could help people improve their focus (Fig. 15). This study was reported in the Proceedings of the National Academy of Sciences (PNAS) in 2004.

In Fig. 15, no matter what kind of analysis the authors used, 40 Hz was a clear frequency band to differentiate the resting state and meditative state. The findings from both Liu et al. and Lutz et al.'s studies indicated that 40 Hz might play an important role in attention induction and attention loss. We thus suggest that researchers could establish a detection mechanism for human attention by detecting 40 Hz in the EEG data, and this attention mechanism could help educators to design suitable curriculums, learning and teaching materials, and appropriate learning and teaching time in each class.

In addition to the research on the influence of affect on scientific creativity, some researchers have discussed gender differences in affective reflections in computer-based learning and assessment. The next section describes this kind of research.

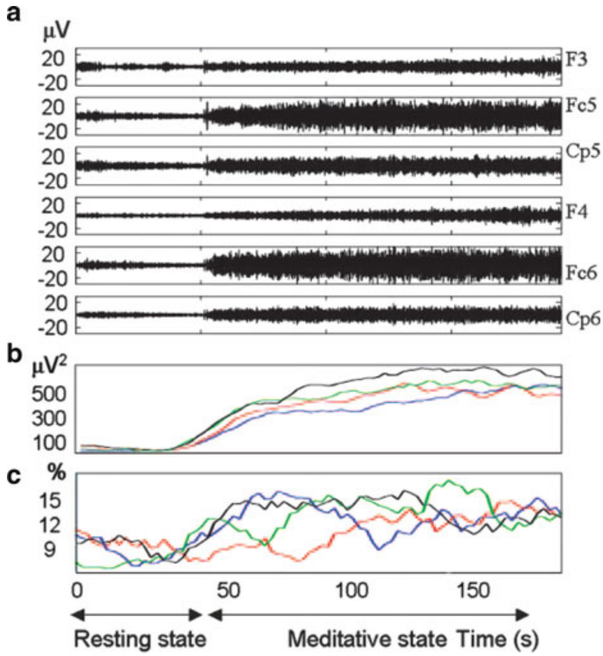

Fig. 15 The high-amplitude gamma activity during mental training: (**a**) raw electroencephalographic signals, (**b**) time course of gamma activity power, and (**c**) time course of subjects' cross hemisphere synchrony between 25 and 42 Hz (Lutz et al., 2004)

6 Gender Differences in Affective Reflections in Computer-Based Learning and Assessment

Assessment is an important part in the education domain to evaluate students' learning achievement, and a self-assessment test system is typically considered as an effective instructional strategy for training students to evaluate their own learning progress and helping them prepare to face anxiety or other affective states during tests (Liu et al., 2013a; Moridis & Economides, 2012). Many previous studies have also mentioned that computer-based assessment (CBA) is more user friendly for student self-assessment (Kaklauskas et al., 2010; Moridis & Economides, 2012). However, in the last few years, many researchers have suggested considering how to promote students' positive affect in a CBA situation since this might be the most effective way to improve the efficacy of CBA testing (Cassady & Gridley, 2005; Economides, 2009; Nicol & Macfarlane-Dick, 2006).

For this reason, Moridis and Economides (2012) adopted applause as an achievement-based reward to promote students' positive affect during a CBA test. They found that adding applause when the students got correct answers on the test was useful for male students to improve their learning achievement, but the response to the reward was less active in the females than in the males. In our lab, we followed Moridis and Economides' research and further adopted EEG methodologies to provide neuroscience evidence to illustrate the phenomenon that

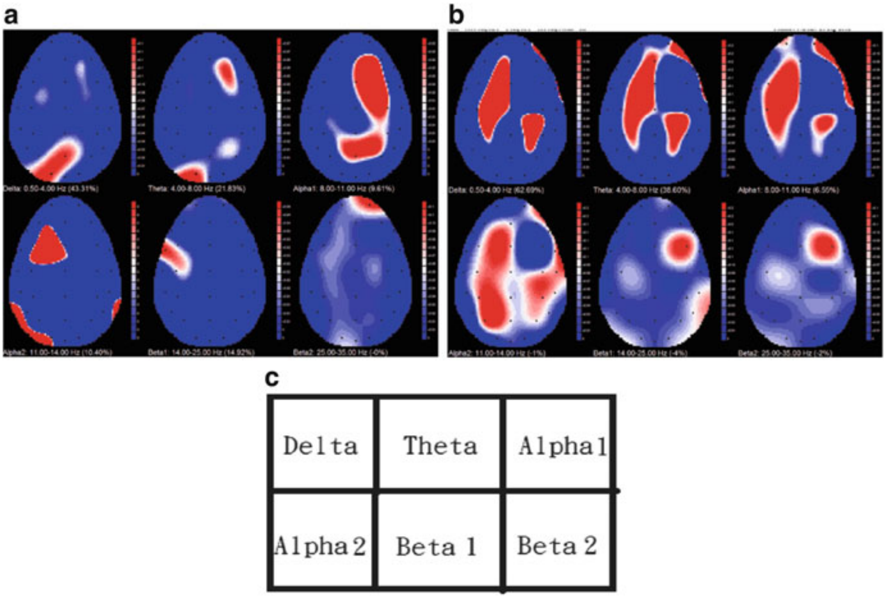

Fig. 16 Analyzed EEG data in the topographical map of the brain (**a**) Females (**b**) Males (**c**) Frequency table (Liu et al. submitted)

applause as a reward is more useful for male than for female students (paper submitted for publication).

In our study, we recorded 15 male and 15 female students' EEG signals when they were completing the experiments. Frequency analysis was performed in the delta (1–4 Hz), theta (4–7 Hz), alpha (8–12 Hz), beta (13–30 Hz), and gamma (>30 Hz) frequency bands. The EEG data for the students answering the test without applause were defined as the baseline, and the EEG data for the students answering the test with applause were used to compare to the baseline.

Figure 16 is the analyzed EEG data in the topographical map of the brain. For the male group (Fig. 16b), the result reveals that the power values of the alpha 1 and alpha 2 frequencies in the EEG data are more active on the two sides of the frontal lobe than they are for the female group. Blackhart, Kline, Donohue, LaRowe, and Joiner (2002) mentioned that the power values of the alpha 1 and alpha 2 frequency bands from the two sides of the frontal lobe are often induced by the appearance of positive affect. In other words, the higher power values of the alpha 1 and alpha 2 frequencies mean more positive affect has been activated. Therefore, the findings prove that the CBA test with applause as reward could promote more active positive affect in males than in females. In other words, it might be useful to encourage male students when they do a good job, but it might not be useful for female students. Male and female students might need different strategies to improve their positive emotions.

Although this finding focuses on the gender differences in affective reflections in CBA, it is an important reflection for all science education. The issue of gender differences in science education, including chemistry education, has long been discussed. Lieberman (2012) also mentioned that it is worth considering the possibility that the social brain's natural tendencies can be leveraged to enhance classroom education. Most of the previous studies have focused on the discussion of the cognitive process of learning. However, we would like to suggest further research to consider the affective aspect of gender differences in science and/or chemistry learning. As already mentioned, the affective dimension can decide students' intentional learning and learning directions. Based on the evidence from neuroscience research, we therefore suggest that teachers should use different strategies to improve male and female students' positive affect and help them promote their learning gains.

Although the affective dimension of chemistry learning by combining neuroscience methodologies is very important, there are also other cognitive dimensions that affect chemistry learning. In recent years, many studies have investigated learners' cognitive processing in science learning. It is important that these studies about learning in science inform future studies about learning in chemistry. The next section introduces those studies which have adopted neuroscience methodologies to explore representation in scientific learning.

7 Representation and Beliefs in Chemistry Learning

Different representations in text may affect students' problem solving, and the application of intuitive rules to proportional reasoning may be enhanced when the problems are presented in different representations (Liu & Shen, 2011). Take Liu and Shen's study as an example; they adopted two kinds of representation of the same problem (Fig. 17). One is the iconic form and the other is the symbolic form.

The participants in Liu and Shen's study were third and fifth grade students. Due to the children's inability to express themselves clearly verbally, the researchers combined eye tracking technology and interviews to explore the influences of representation on the students' learning (Fig. 18). The eye tracking technology is also an important and novel neuroscience technology in the present day. In Fig. 18, the results of their study indicated that representational types and scan paths appear

Fig. 17 Samples of the same problem with different representations: the *left* is the iconic form and the *right* is the symbolic form (Liu & Shen, 2011)

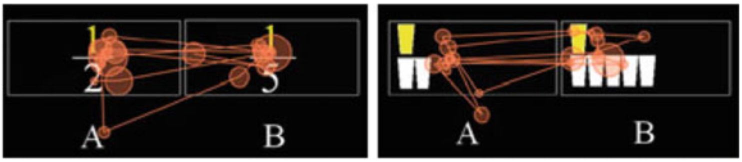

Fig. 18 Data analysis using eye tracking (Liu & Shen, 2011)

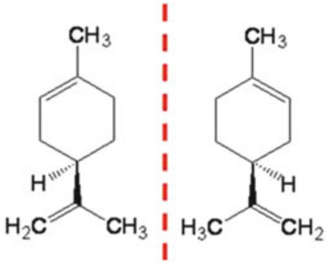

Fig. 19 An example of different enantiomers of molecules

to impact students' problem solving at different developmental stages. This conclusion indicated that different representations would be appropriate for different ages of students in science or mathematics learning.

In chemistry learning, chemical knowledge constructs are learned at the level of the submicroscopic world, and an understanding of chemical structures is considered the foundation of chemistry learning. One of the most important issues in chemistry learning is identifying chemical structures in organic chemistry; a misunderstanding of these structures will cause difficulties in distinguishing different enantiomers (Fig. 19) of molecules and in determining molecule polarity, leading to a failure in understanding of the physical and chemical properties. The most difficult aspects of identifying chemical structures are the definitions and transfer of two-dimensional (2D) and three-dimensional (3D) chemical structural formulas (Gilbert & Treagust, 2009; Huang & Liu, 2012).

There are many cognitive and affective dimensions which influence the identification of 2D and 3D chemical structural formulas. Huang and Liu (2012) focused on the influences of mental rotation on identifying such formulas, as the role of mental rotation in such tasks was not clear in the previous studies. Some previous studies had indicated that mental rotation affects the identification and learning of chemical structural formulas; therefore, the high-achieving students used more mental rotation to identify chemical structural formulas (Korakakis, Pavlatou, Palyvos, & Spyrellis, 2009). However, some researchers had argued that low-achieving students may need to identify chemical structural formulas with mental rotation, whereas high-achieving students do not (Hegarty, 2004; Stieff, 2007). To clarify this issue, Huang and Liu (2012) adopted the ERP methodology to explore the role of mental rotation in identifying 2D and 3D chemical structural formulas.

The results of their study showed that, through the ERP data, the high-achieving students did in fact perform mental rotation more often in identifying 2D chemical structural formulas than the low-achieving students since the amplitude of rotation-related negativity potentials is larger for high-achieving students than for low-achieving students. That is to say, the low-achieving students used similar cognitive processing to identify 2D figures and chemical structural formulas. To sum up, Huang and Liu (2012) summarized that the reason low-achieving students used less mental rotation to identify 2D chemical structural formulas than high-achieving students is because the low-achieving students did not realize that the 2D chemical structural formulas were projections of 3D chemical structural formulas; hence, they used the mental rotation which they used in identifying 2D figures to identify 2D chemical structural formulas. However, mental rotation is an inappropriate strategy in this case. The evidence was also supported by the students' interview data.

The results of this study not only reflected the different strategies which high- and low-achieving students adopt in identifying chemical structural formulas but also revealed the students' different beliefs regarding the nature of the representations of chemical structural formulas. Many previous studies had indicated that assisting students to understand chemical structural formulas well should be established in the virtual and real models and representations of chemical structural formulas (Gilbert, 2008; Mathewson, 1999; Moè, 2009; Núñez-Peña & Aznar-Casanova, 2009; Seddon & Eniaiyeju, 1986; Stevens, Delgado, & Krajcik, 2010; Wu, Krajcik, & Soloway, 2001). However, in Huang and Liu's study, they mentioned that many low-achieving students rotate the 2D chemical structural formulas (Fig. 20b) as 2D figures because they believe that a chemical bond is a real physical bond in the representation of 2D chemical structural formulas (Fig. 20a), and so they rotate the chemical structural formulas in the same way as 2D figures in daily life.

In the practice of chemical education, many teachers and textbooks use ball-and-stick models to demonstrate chemical structural formulas (Frailich, Kesner, & Hofstein, 2009; Huang & Liu, 2012; Stevens et al., 2010), but if the limitations of the analogies of these models are not emphasized, the students might believe that the chemical bond is a real physical entity and use daily life experience to rotate the

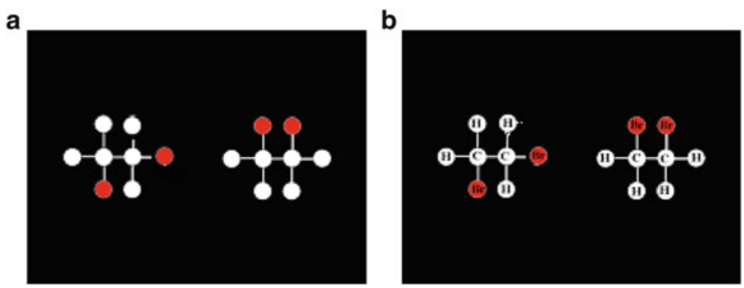

Fig. 20 An example of 2D figures and 2D chemical structural formulas (Huang & Liu, 2012)

2D chemical structural formulas as they do real 2D objects (Boo, 1998; Huang & Liu, 2012; Mathewson, 1999; Moè, 2009).

The findings remind science teachers to avoid only introducing one kind of representation, and that they also need to pay more attention to students' understanding regarding representations in their chemical learning.

8 Implications for Teaching and Learning

There are many opinions and case studies presented in this chapter. Based on the scientific evidence from neuroscience data, these research studies and practice suggest that specific teaching and learning strategies may improve the effectiveness of teaching and learning chemistry. The following are some suggestions:

(a) Scientific creativity is an important element in chemistry learning, and it will be more fruitful with negative than with positive affect. Hence, teachers should consider what makes a suitable negative affect environment, such as a stressful or pressured learning environment, which might help the students improve their performance. We suggest that teachers could limit the time for students to complete a task to create a certain amount of stress or pressure.
(b) Teachers might consider the affective aspect of gender differences in chemistry learning. They should use different strategies to improve male and female students' positive affect and help them improve their confidence and promote their learning gains.

The main idea in this chapter is that the affective dimension can decide students' intentional learning and learning directions. That is the most important original point in learning. The affective dimension includes both emotions and beliefs. This chapter has introduced some thinking about the affective dimension and chemistry learning based on research and practice; for example, the affective dimension influences students' understanding of representation, students' scientific creativity, and students' confidence and performance in chemistry learning. Teachers, teaching material designers, and educators should all consider these findings and try their best to help students promote their intentional learning.

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Evaluating Drawings to Explore Chemistry Teachers' Pedagogical Attitudes

Silvija Markic and Ingo Eilks

Abstract Based on a review of a set of studies conducted by the authors, this chapter discusses the potential of using drawings of classroom situations to explore, research, and assess the pedagogical attitudes of chemistry teachers and teacher trainees. Justification is given for using such drawings to gain insights into teachers' pedagogical attitudes. Two methods for evaluating beliefs and pedagogical attitudes will be outlined and illustrated by prototypical examples. Implications for teacher education will also be discussed.

1 Drawings and Attitudes

For decades drawings and visual imagery have been used as markers or "mirrors" of personal identity (Weber & Mitchell, 1996). The discipline of art therapy views drawings as key tools for understanding patients' thoughts and feelings, including helping them making sense of their current life situation. Adler (1982) showed that drawings offer not only a chance to reflect upon personal feelings and attitudes toward certain people or situations but also an opportunity to communicate cultural issues and values which are prevalent within a specific living environment.

This paper discusses the use of drawings in teacher education. Thomas, Pederson, and Finson in 2000 suggested the use of drawings to explore, research, and assess pedagogical attitudes of science teachers toward student- vs. teacher-centeredness. Their original idea was further developed by Markic and Eilks (2008) for getting a broader view into chemistry teachers' beliefs and attitudes toward classroom organization, the objectives of chemistry education, and the way chemistry should be taught. In a set of studies, drawings of classroom situations were used to analyze and compare chemistry student teachers' and experienced teachers' respective beliefs with their counterparts from other science teaching domains (Markic & Eilks, 2008), at different phases of their teacher education program

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(Markic & Eilks, 2013) or in the foreground of different educational systems and cultures (Al-Amoush, Markic, Usak, Erdogan, & Eilks, 2013).

Weber and Mitchell (1996) suggested that drawing and visual imagery offer individuals an alternate pathway for making sense of things as compared to words in the form of text or speech. Based on the studies mentioned in the last paragraph, this paper reflects the potential of drawings to explore student teachers' and teachers' pedagogical attitudes. This is done by drawings since drawings can express things, (1) which are difficult to explicitly formulate in words, (2) which have not been completely thought through, or (3) which are indescribable, indefinable, and/or quite often subconscious in nature. By 1971, Langer had already suggested that a drawing

> . . .objectifies sense and desire, self-consciousness and world consciousness, emotions and moods that area generally regarded as irrational because words cannot give us clear ideas of them. But the premise tacitly assumed in such a judgment—namely, that anything language cannot express is formless and irrational seems to be an error. (Langer, 1971, p. 91)

In the nineteenth century, mental image research had already been started by Galton (1880). It went on to become one of the main research foci of the early twentieth century (see Betts, 1909 and Titchener, 1909). However, interest in mental images decreased over time. The reason for this was that mental representations and images were considered to be too private and individual. It was even suggested that visual imagery—contrary to a person's behavior—cannot be objectively seen, quantified, or controlled by another person. Mental images can only be described and presented by the person who expresses them. This means that many problems in using mental images for research purposes were recognized early on. It was expected that visual imagery can be misinterpreted either consciously or inadvertently. This is why the proponents of behaviorism argued that visual imagery is not a topic which can be investigated with sufficient scientific rigor or control (Galotti, 1998).

In the late 1960s, research on mental representations found a new beginning with the advent of cognitive psychology. There were two reasons for this. First, interest in developing tests for therapy methods based on drawings was still existed (Sheehan, 1967). Second, mental imagery was still viewed as an essential part of an individual's cognitive processes and therefore could not be ignored in any comprehensive model of human cognition (Shepard, 1975). The discussion of mental images, representations, and their importance for cognitive psychology remained controversial for a long time (Paivio, 1971). There was a debate as to whether drawings mirror the images that one person has in mind or whether they should be interpreted as allegories. The functional-equivalency hypothesis finally showed that mental images are closely connected to a person's cognition and attitudes (Kosslyn, 1980; Shepard, 1978). They are closely related to the reality that a person conceptualizes for any object or event. Today, visual imagery has regained its credibility as a worthwhile topic among most cognitive psychologists.

Nowadays, drawings are an accepted tool in cognitive psychology when it comes to gaining insights into a person's mental representations. Mental images are seen as a basic element for understanding the structure of an individual's mind and thinking processes (Solso, 2005). Weber and Mitchell (1996) define an image to be "…an idea or mental representation, a conception with a visual or physical flavor, an experiential meaning, a context or history, with a metaphorical, generative potential" (Weber & Mitchell, 1996, p. 305).

They suggest that images are produced as a form of text that can be "read" and understood, because images are believed to possess a communicative function, too. Weber and Mitchell also showed parallels between drawings and sketches when compared to text and speech. The goal of written text or speech is to transfer a vivid mental picture for the reader. A written text paints a picture using words, while drawings and sketches use lines, curves, and colors to express the same thing (Weber & Mitchell, 1996). Bullough, Knowles, and Crow (1991) stated that using images and drawings in the sense of their metaphorical power can both represent the building blocks of a given person's thinking and also be used as a tool for assessing knowledge.

Wilson and Wilson (1979) also stated that image making is an important characteristic of humans making sense of their environment. Images are constructed to make sense of experiences and information, so that they can be communicated to others. Such images (in our case drawings produced by chemistry teachers and teacher trainees) can be considered to represent an important bundling of information which can be understood and decoded by researchers. Drawings usually provide unique insights into human sensemaking which normally are not easily discernible if written or narrative texts are used. Drawings are useful tools for expression, since one can portray things which in many cases cannot be textually described or which deviate widely from typical written or oral descriptions. Drawings and pictures are both helpful instruments for evaluating and bringing to light teacher identity, which often remains unseen, which is influenced by past and present experiences, and which may contrast with teachers' stated identities and practices (Weber & Mitchell, 1996). However, it should also be stated that drawing spontaneous images quite often is simply a "snapshot method," which identifies rather spontaneous imagery centering around specific aspects of teaching life.

2 Drawings in Chemistry and Science Education in General

The use of drawings as a tool for gaining better insight into psychological processes is not a new idea in educational research. By the early twentieth century, Goodenough (1926) had already explored children's drawings in order to evaluate intelligence. Arnheim (1956), Piagret and Inhelder (1969), and others also researched children's intelligence levels and their emotional and cognitive development using drawings in various case studies. This has also been the case in science education. Using Goodenough's (1926) "Draw-A-Man-Test" as a starting

Fig. 1 Examples from the study by Laubach et al. (2012)

point, Chambers (1983) developed the "Draw-A-Scientist-Test" (DAST) in order to evaluate children's perceptions of scientists. Chambers found that the older children are, the more stereotypical and standardized their personal beliefs about scientists become (Schibeci & Sorensen, 1983). Other studies which employed DAST evaluated: (1) elementary students' beliefs about who actually performs science under given conditions (Barmann, 1996); (2) precollege students' ideas about science, scientists, and technology (Hill & Wheeler, 1991); and (3) students' beliefs about scientists concerning gender differences (Mason, Kahle, & Gardner, 1991). Quite recently, Laubach, Crofford, and Marek (2012) inquired into Native American students' perceptions of science using the same instrument. They came to the conclusion that students who practice native cultural traditions at home do not tend to view themselves as scientists. The researchers suggested that such a viewpoint may influence students' educational and career choices in the fields of science and technology. Two examples from their study are given in Fig. 1.

In 1995 Weber and Mitchell pointed out that while many researchers have recognized the power of children's drawings as a diagnostic tool for more than a century, educational research generally has not paid enough attention to this area. This has changed, however, in recent years. Ever since the 1990s, DAST and other related tools have again begun to be employed for research on science teachers' beliefs and attitudes. Rosenthal (1993) used DAST to evaluate the beliefs of 76 teacher trainees of elementary school science and 90 student teachers of biology. He found that the scientist stereotype held by both groups consisted of a white male wearing eyeglasses and lab coat working in a laboratory. Elementary teachers tended to hold more closely to this stereotype than secondary school teacher trainees in biology did. Carnes (2000) also evaluated student teachers' beliefs when comparing early childhood and elementary school situations. Many students at the beginning of their Master of Arts program expressed beliefs coinciding with the "mad scientist" stereotype of scientific disciplines. The "mad scientist" is typically portrayed as a Caucasian scientist of either gender who is engaged in a variety of wild scientific investigations. He or she is an adult and typically works alone in a white lab coat, wears spectacles, and has a weird hairdo like in the world-famous photograph of Albert Einstein. Test tubes and other glassware are always scattered on the nearby workbench or are held in the scientist's hand. Usually there are containers which are either smoking, boiling, or bubbling. Very few modifications of these beliefs were found to have taken place after the courses were completed. The largest change merely featured the inclusion of children in the overall picture.

Starting with these research projects, Finson, Beaver, and Crammond (1995) developed the "Draw-A-Scientist-Test Checklist" (DAST-C) to more easily evaluate and compare drawings concerning scientists. The checklist consists of a list of indicators for seven stereotypical elements which were identified by Chambers (1983). It also contains eight additional items identified as stereotypical elements typically found in students' drawings. Test objects receive a score of "1" when indicators exist in the drawing or "0" for nonexistent features. The points are added together to calculate a final score. Applying this analysis tool has shown that significant shifts in stereotypical images of scientists occur toward a more realistic view of everyday people involved in the scientific endeavor as the level of personal student contact with real-life scientists goes up. This instrument has seen growing use in educational research since its initial publication. It has been successfully used for different populations and age groups. A review of the use of DAST and DAST-C can be found in Finson (2002).

Thomas et al. (2000) later shifted their focus to the "Draw-A-Science-Teacher-Test Checklist" (DASTT-C). This tool does not evaluate beliefs about scientists but rather focuses upon science teachers' and science student teachers' beliefs about teaching science. The task was changed to: "Draw a picture of yourself as a science teacher at work." This question forces teachers and teacher trainees to deeply involve themselves in a hypothetical classroom situation while simultaneously drawing an image of themselves and their students in action. For better comprehension of the resulting pictures, Thomas, Pedersen, and Finson (2001) added two further questions about the drawings. These allowed the researchers to pinpoint additional information and shed light on certain aspects and components in the drawings. The questions inquire into the activities of the teacher and of the students. The final version of DASTT-C consists of two pages. The first page contains a blank square in which the drawing is to be made. The second page presents the two open-ended questions, which ask about which actions the teacher and the students are performing in the picture. Thomas et al. (2001) have also developed a checklist for their research tool, which allows them to assess teacher beliefs and pedagogical attitudes of the participants with regard to the teacher-centeredness or student centeredness of lessons. The checklist contains three sections for evaluation: *teacher, students*, and *environment*. A total of thirteen attributes have been worked out. The number of attributes occurring in a drawing allows consideration of the prevalence of teacher-centered or student-centered personal beliefs among the participants. Finally, Markic, Valanides, and Eilks (2008) developed a broader and more qualitative application of the idea using DASTT-C as a starting point. They added two more questions to the second page for an even better and deeper

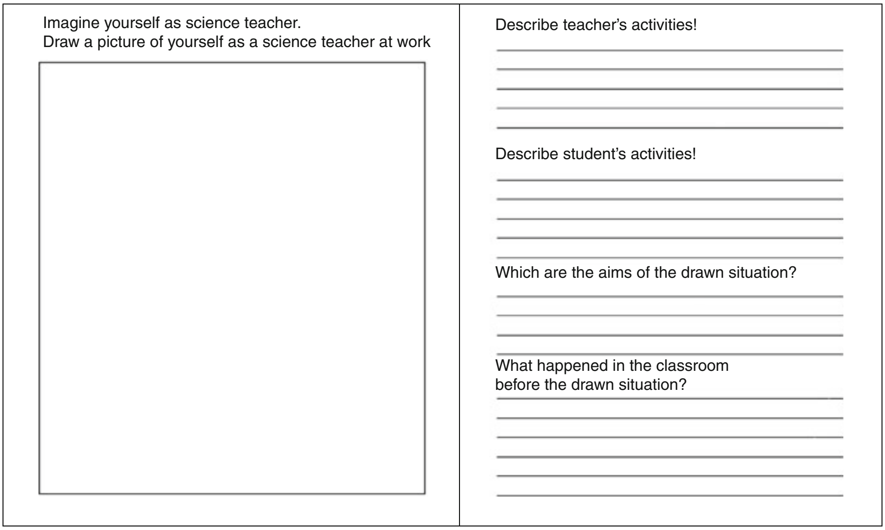

Fig. 2 The modified version of DASTT by Markic et al. (2008)

understanding of the details found in the drawings. These new questions relate to teaching and learning objectives and to the teacher's approach with respect to the teaching situation drawn in the test. To allow for evaluating the extended tool, a detailed evaluation manual was also developed on the basis of Grounded Theory. Both applications of DASTT-C, the original and the extended one, are discussed in detail below. The final questionnaire which was also used in the studies described in this paper can be found in Fig. 2. The focus of the research by Markic et al. (2008) was to use the modified DASTT-C to explore the beliefs and pedagogical attitudes of chemistry student teachers and experienced teachers, making them explicit and relating seminar content in teacher education with beliefs and attitudes presented in the study. External references to beliefs of biology and physics teachers were also explored to better understand how and where chemistry student teachers and experienced teachers depend on the subject they are teaching or attending to teach. The drawings were also used to analyze to which extent change in attitudes and beliefs toward classroom organization, teaching style, and the objectives of learning chemistry might occur during teacher education.

3 Evaluating Drawings to Explore Chemistry (Student) Teachers' Pedagogical Attitudes

3.1 The Original Approach to DASTT-C

Thomas et al. (2001) suggested using a quantitative approach for evaluating the DASTT-C drawings of classroom teaching situations in science education. DASTT-C employs a 13-point rating system in the form of a checklist. This checklist consists of sections examining three areas: teacher, students, and environment. Each section covers a small number of attributes, which are rated as to whether or not they appear in the drawings. The *teacher* and *student* sections were both subdivided into items dealing with *activity* and *position*. The *teacher activity* section registers the types of activities and actions which teachers may typically perform in the science classroom (such as lecturing, using visual aids, etc.). The division denoting *position* marks the teacher's location in the classroom and his/her posture (e.g., centrally located with erect posture). The *student activity* section records the types of student activities typically present in the classroom (watching, listening, performing tasks while seated, etc.). The subsection for student *position* notes whether or not the learners are seated in rows. The third and final part of the checklist, *environment*, lists the circumstances under which science instruction occurs, for example, whether instruction is carried out indoors or outdoors. Other factors include the presence of laboratory materials or equipment on desks; the presence of symbols from science, math, or technology; etc. The entire checklist is presented in Fig. 3.

Each of the attributes presented in the checklist is an indicator of a teacher-centered approach of teaching. It receives a score of either "1" or "0," which indicates the presence or absence of the given attribute, respectively. Total scores range from 0 to 13 with the lowest totals representing more student-centered teaching situations. Scores falling between 0 and 4 indicate a student-centered attitude to teaching science and scores landing between 7 and 13 a fairly teacher-centered attitude. Scores of 5 or 6 allow no decision to be made in any given direction (Thomas et al., 2001).

I. TEACHER

Activity

Demonstrating experiment / activity
Lecturing / giving directions (teacher talking)
Using visual aids (chalkboard, overhead, and charts)

Position

Centrally located (head of class)
Erect posture (not sitting or bending down)

II. STUDENTS

Activity

Watching and listening (as suggested by teacher behavior)
Responding to teacher / text questions

Position

Seated (as suggested by classroom furniture)

III. ENVIROMENT

Inside

Desks are arranged in rows (more than one row)
Teacher desk/table is located at the front of the room
Laboratory organization (equipment on teacher desk or table)
Symbols of teaching (ABC`s, chalkboard, bulletin boards, etc.)
Symbols of science knowledge (science equipment, lab instruments, wall charts, etc.)

TOTAL SCORE (PART I+II+III) =

Fig. 3 DASTT-C score sheet (Thomas et al., 2001)

3.2 An Extended Approach to DASTT-C

Applying DASTT-C to student teachers and teachers from different science subjects and countries, one eventually assumes that much more information about student teachers' beliefs might exist in the data than "simple" insights into student- or teacher-centered teaching approaches. This is why Markic et al. (2008) started operating a new qualitative and extended approach to evaluate DASTT-C-related data to reveal the full potential implied in the teachers' and student teachers' drawings. Two more questions were added to DASTT-C, and Grounded Theory (Glaser & Strauss, 1967) was operated to reveal the full content of the data. Grounded Theory allowed analysis without explicit theoretical assumptions and also the use of collected data to steer the overall process of analysis toward its maximum potential.

In applying Grounded Theory (GT), all information from the student teachers' and teachers' drawings and narratives were identified, marked, and labeled, providing most possible information related to teaching methods, content, teaching objectives, textual approaches, media, etc. More than 300 codes stemming from the process of open coding were created to describe the data, such as: "teacher is standing in front of the class," "students conduct experiments," "students are not in the classroom," "objective is to learn about the pendulum," etc.

From this rich source of information, axial coding was carried out by cyclically refining and systematically grouping the information step by step into smaller numbers of categories. The grouping was done by combining closely related aspects (e.g., learning about content is a central objective, but this objective is illustrated by different contents). Elements were also grouped according to causal relationship. For example, students sitting in rows with the teacher in front of the class indicated a teacher-centered style of teaching. Using the overhead projector was an indication of believing teaching to be a case of "I explain the content to my students." The demonstration of experiments was classified as a way to illustrate knowledge to students, etc. Each step was communicatively validated within the research group and compared to the original data. Finally, only three axial coding categories encompassing almost all the codes were created. They related to *beliefs about classroom organization, beliefs about teaching objectives,* and *epistemological beliefs*.

Through selective coding, a core category was constructed to explain the three categories from axial coding, based on a commonsense approach. The core category encompasses the spectrum between more traditional beliefs about science teaching and beliefs more in line with modern education theory. The term "traditional" is characterized by teacher-centered classroom organization, objectives oriented on exclusively teaching science facts and the structure of the discipline, and a transmission-oriented view of teaching and learning. The "modern" end of the spectrum is comprised of and characterized by a student-oriented classroom organization, belief in the value of general educational objectives in the means of a scientific literacy for all, and constructivist learning. Another aim of selective coding is filling in categories, determining properties, and specifying dimensions. For the purpose of refining and developing the three abovementioned categories, each of them was assigned a range (in GT called "dimensions") of numbers from −2 to +2. The numbers symbolize descriptors within each of the categories using ordinary but nonlinear scales. The scales and descriptions are presented in Table 1.

Finally, a graphic approach for representing the data was selected in order to allow both groups and individuals to be compared and contrasted. The three axial coding categories were introduced into the diagram in order to create 3D-pictorial representations. The placement of each participant's code combination within this 3D area gives researchers a comprehensive overview of a given individual's beliefs when the graphic is expanded in the three dimensions (Markic & Eilks, 2008). The closer a subject's code combination approaches the lower, left, frontmost part of the three-dimensional plot, the more traditional the expressed beliefs of teaching and learning are. Code combinations forming in the upper, right, hindmost corner of the diagram indicate that a participant's beliefs fall in line with modern educational theory. Examples of two such diagrams are given in Fig. 4.

Table 1 Scales and description of the codes from selective coding

Beliefs about classroom organization	−2	Strongly teacher-centered: The teacher is at the center of any activity, dominates any activity, lectures, and uses media to focus students' attention
	−1	Rather teacher-centered: The teacher is at the center of the activity but interacts with the students; she/he requires short answers from students but dominates and supervises every activity in the classroom
	0	Neither . . . nor: Teacher- and student-centered activities are in balance; the teacher shifts from teacher- to student-centered teaching
	1	Rather student-centered: Student activities are at the core, but teacher initiates and controls all student activities
	2	Strongly student-centered: Student activities are at the core; students are at least partially able to choose and control their own activities
Beliefs about teaching objectives	−2	Exclusively content-structure focused: Learning content knowledge is the central objective
	−1	Rather content-structure focused: Learning content is in the foreground, but some noncognitive objectives are targeted
	0	Neither . . . nor: Learning about content and applications or noncognitive objectives is balanced; motivational objectives are possibly at the core
	1	Quite scientific literacy-oriented: Learning of competencies, problem-solving, and thinking in relevant contexts and other affective outcomes are important
	2	Strongly scientific literacy-oriented: Learning of competencies, problem-solving, and thinking in relevant contexts and other affective outcomes are the main focus of teaching
Epistemological beliefs	−2	Learning is receptive: Learning is passive and supervised; learning is a dissemination of information
	−1	Supervised learning with student-active phases: Learning follows a storyboard written by the teacher, conducted by the students, but organized and supervised by the teacher
	0	Supervised learning with elements of constructivism: Learning is supervised by the teacher but takes students' preconceptions into consideration or problem-solving is used; the learning process remains supervised
	1	Rather constructive learning: Learning is an autonomous and self-directed activity but is initiated and partially directed by the teacher
	2	Strongly constructive learning: Learning is an autonomous and self-directed activity and begins with students' ideas and initiatives

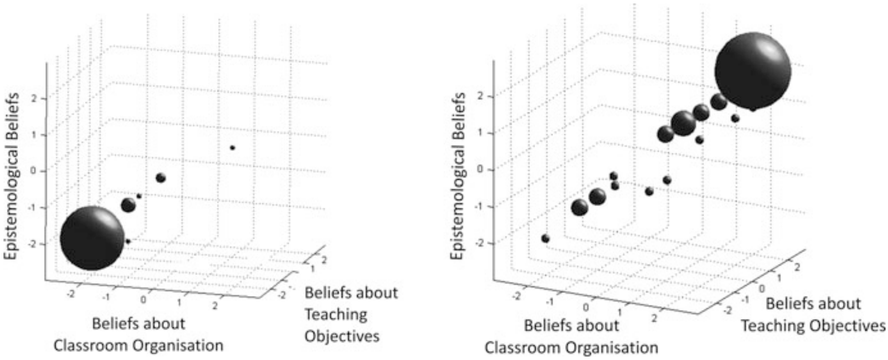

Fig. 4 Examples of diagrams for 3D representations with a majority of participants holding traditional (*left*) or modern (*right*) beliefs, respectively. This way of representing the data allows a direct impression of the average prevalent beliefs in a group of student teachers or teachers

4 Examples of Drawings in Science Education

The DASTT-C reveals a broad variety of mental images among chemistry teachers and teacher trainees. The section below presents several prototypical examples of participants' drawings of classroom situations in the subject of chemistry.

4.1 Example 1

This first example (see Fig. 5) comes from a freshman student teacher of chemistry who had just entered a university teacher education program. We can assume that most of the imagination and attitude shown toward chemistry teaching in this case stems from this young person's past experience as a pupil in school, mass media input, and both peer group and societal influences. This particular drawing portrays a very structured chemistry classroom situation. This represents the attitude that chemistry classrooms are quite regularly teacher-centered and traditional in their makeup.

Analyzing this drawing with the help of the checklist from Thomas et al. (2001), we see that the teacher is in the middle of the classroom and keeps her posture erect. The teacher is lecturing and demonstrating an experiment. She is also using a projector and a blackboard to focus the attention of her students on one point. The pupils assume a passive role. Most of them are not paying attention to the teacher (especially the student in the first row on the extreme right). Most learners are looking bored, and they are not actively participating in the class. Additionally—with regard to the checklist—all of them are sitting. The student desks are all in rows. The teacher's desk is at the front and center of the classroom, and there is scientific equipment on it. Furthermore, several symbols of science teaching (a blackboard, etc.) and symbols of science knowledge (an experiment on the floor) are presented in

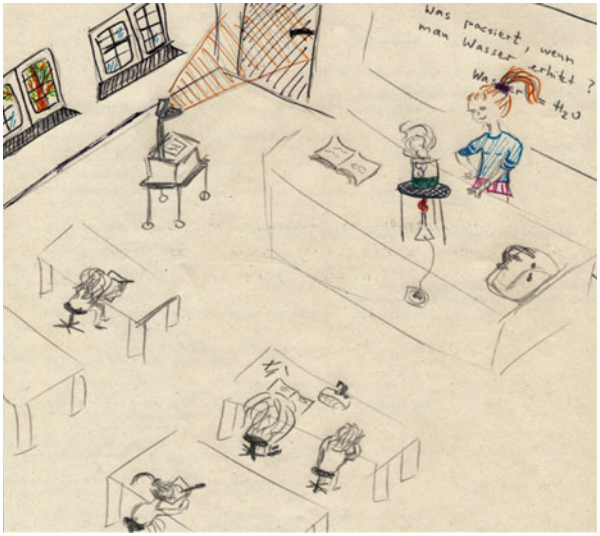

Fig. 5 Example representing a strongly teacher-centered, traditional approach to teaching and learning chemistry

the drawing. Many attributes of a teacher-centered attitude to chemistry teaching are presented by this image.

A similar focus is derived by the application of the Grounded Theory (GT)-based evaluation grid. The teacher remains at the center of all activity, dominating both through her actions and lecturing. Furthermore, she uses media to focus the students' attention. When it comes to epistemology, we can say that learning seems to be considered as a receptive process in this drawing. Learning is passive and supervised. It is portrayed as the dissemination of information. Additionally, the teacher trainee wrote "comprehending scientific concepts" when asked about objectives of the situation. The teaching objectives listed by the participant proved to be exclusively content-structure focused.

4.2 Example 2

The second example (Fig. 6) also shows the chemistry teacher with erect posture, standing in the center of the classroom. Once again, the teacher is giving a talk and is discussing a formula written on the blackboard. The students are also seated in rows. This drawing again shows a mainly teacher-centered approach of teaching and learning. This participant's pedagogical attitude is not principally in conflict with the traditional attitude toward teaching chemistry. However, in contrast to Example 1, the situation in Example 2 shows much more active students. In the drawing, we can see that the pupils are working either with books or work sheets.

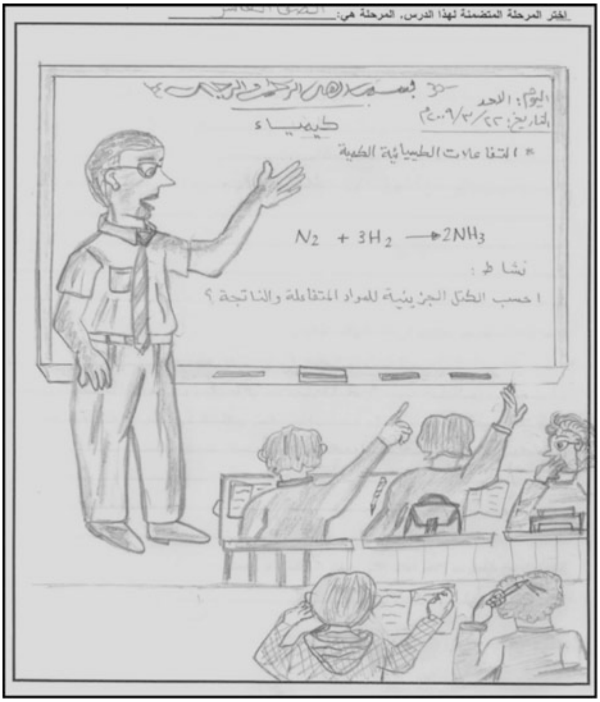

Fig. 6 Example representing a mainly teacher-centered, traditional approach to teaching and learning chemistry

They are at least partially participating in the lesson by providing answers or comments to the teacher. However, this situation is still rather teacher-centered. The teacher stands in the center of activity but interacts with the students. He requires answers from them but still dominates and directs every activity in the classroom. The teaching-learning process is supervised by the teacher but includes some smaller, student-active phases. Learning follows a storyboard written by the teacher and conducted by the students, but it is solely organized and directed by the teacher.

4.3 Example 3

Example 3 (Fig. 7) is much different than the first two examples above. The main difference is that the pupils are not seated in rows but rather in circles of desks. It appears that the students are moving all around the classroom. It is not easy to recognize the teacher in this picture. The teacher is shown in the left, lower corner of the drawing (marked with "Ich" which means "I"). Analyzing this drawing using the checklist reveals that there are very few attributes indicating a teacher-centered

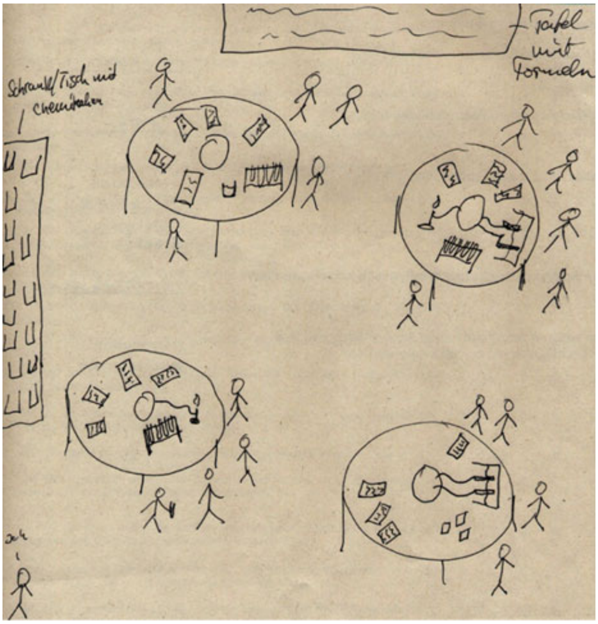

Fig. 7 Example representing a mainly student-centered, modern approach to teaching and learning chemistry

attitude in this classroom. We see only symbols of teaching and symbols of scientific knowledge in this picture. This drawing represents a rather student-centered situation. Based in the qualitative interpretation pattern, this drawing can be considered to be quite modern in its educational attitude. Student activities are at the core, even if the teacher still initiates and controls learners' activities. Pupils can be seen working in groups, based upon materials which were organized and provided by the teacher. Although the teacher still controls the student activities in this picture, learning becomes constructivist rather than receptive from this point onward. It changes into an increasingly autonomous, self-directed activity free of the teacher, even though the picture and narrative reveal that the teaching and learning process was thought to be initiated and directed by the teacher. The narrative also made it clear that the learning of competencies, problem-solving, critical thinking in relevant contexts, and other affective outcomes were recognized teaching goals, even if the learning of scientific facts and theories remained the major aim.

4.4 Example 4

In the fourth example (Fig. 8), it is even more difficult to recognize the teacher. In most extremely student-centered, modern drawings, the teacher is shown performing activities together with the pupils (collecting data, planting, etc.) without playing a specific role. Arrows are often used to show that the teacher is

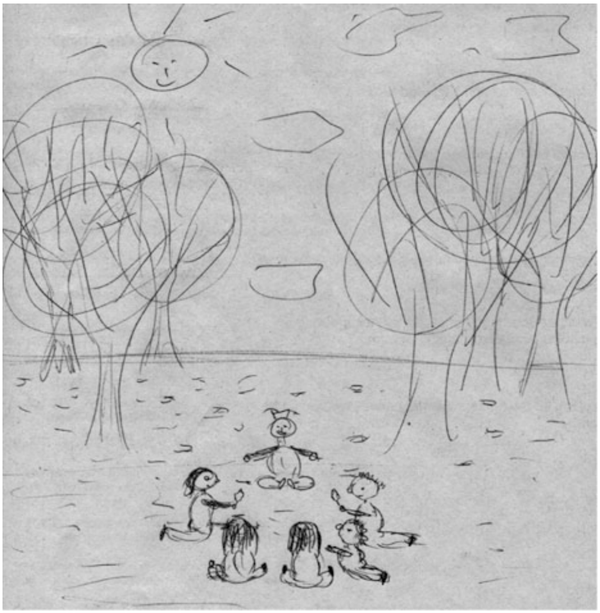

Fig. 8 Example representing a strongly student-centered, modern, open approach to teaching and learning chemistry

moving around the classroom providing advice or checking out problems or difficulties. In classroom lessons, students are usually depicted sitting in small, cooperative groups. In most student-centered pictures, the lesson does not even take place inside a classroom, just as we see in this example. Students are often depicted outside of the school building (e.g., near a forest or lake). When the lesson does take place in a classroom, the learning environment often shows "normal" tables for students but also includes extra tables for experiments and for scientific equipment meant to be used by students. In this drawing, we recognize that the lesson is taking place in the forest. The students and teacher are seated between the trees. We only can assume that the person sitting in the middle of the picture and looking at us is the teacher. There are no differences in size, appearance, or activity among the figures in this picture. In the connected narrative, the learning is described as strongly constructivist. Students begin learning activities autonomously and in a self-directed fashion. They decide what they want to explore in the environment and what is interesting for them personally. The "classroom" situation is also strongly student-centered. Student activities form the core, with the pupils able to choose and control their own activities.

5 Research Applications of Classroom Situation Drawings of Chemistry Teachers' Pedagogical Attitudes

Thomas et al. (2000) evaluated 27 preservice elementary teachers' beliefs about themselves as science teachers using DASTT-C. The questionnaire was administered during the very first meeting of their science methodology course. The researchers came to the conclusion that preservice teachers largely base their beliefs on their own experiences as elementary school students. Furthermore, the study showed that students who chose to become teachers have a positive identification with teaching. Louca, Riges, and Valanides (2003) used the same instrument in Cyprus for a study of student teachers' beliefs about science teaching in primary school science. This study evaluated the effects which taking a course in science methodology had upon student beliefs about teaching. The results show that the student teachers' beliefs had changed after completion of the course. Before attending the course, only 6 % of the student teachers possessed student-centered beliefs (69 % teacher-centered). After the course was finished, 25 % of the student teachers held student-centered beliefs (44 % teacher-centered). In an international comparison study, student teachers' beliefs about science teaching in both Cyprus and Germany were evaluated (Louca, Riges, Eilks, & Valanides, 2006). The results showed (more or less) the existence of the same beliefs in both countries. However, differences existed between student teachers who had received less training and those with more overall training. This is quite characteristic for both German and Cypriot student teachers. Both groups appeared to shift toward more student-centered viewpoints as they got closer to the end of their teacher training.

Markic and Eilks (2013) also evaluated the influence of education on prospective teachers' beliefs and attitudes in the case of German chemistry teacher training. They carried out a cross-level study based on drawings by both chemistry student teachers and teacher trainees. Data was collected from freshman student teachers, a group of student teachers after their first school internship halfway through the university teacher education program, and, finally, a group of chemistry teachers who had just completed the teacher education program and begun compulsory in-service training to earn their teaching license. The results show that freshmen student teachers mainly express very traditional beliefs about teaching and learning (characterized by teacher-centeredness and an understanding of teaching and learning as pure knowledge transfer). A comparison with freshman student teachers in other science teaching domains (secondary school physics, biology, and primary school science) revealed that chemistry and physics students were much more traditional in their educational beliefs and attitudes when compared to biology or primary school science education (Markic & Eilks, 2008). In the cross-level study, the student teachers after their first school internship and the group of chemistry teachers held more modern beliefs about teaching and learning, which are in line with modern educational theory. Comparing the latter two groups showed that student teachers midway through their training appear to have the most modern teaching beliefs. Chemistry teachers which finished their teacher training were holding as well modern beliefs but not such strong as the one halfway through their university teachers training program. This shows that teacher education can have a positive influence on the development of science teachers' beliefs about and attitudes toward modern, student-active teaching and learning. This fact was also revealed in the study by Katz et al. (2011), who used another qualitative method for analyzing the drawings of student teachers, their mentors, and university researchers.

Using the same instrument, Al-Amoush, Markic et al. (2013) also began evaluating the influence of teacher education systems and cultural differences on student teachers' beliefs about teaching and learning. Data sets from Germany, Jordan, and Turkey were compared. The results show that Jordanian chemistry teachers and teacher trainees held the most traditional, teacher-centered, and transmission-oriented beliefs, while the German sample evidenced the most modern beliefs about teaching and learning. Turkish teachers expressed moderate beliefs, which tended to fall between the two extremes but still could be positioned more closely to the traditional way of thinking. Reflection upon these three teacher education systems and the differences in cultural values between the three countries allowed the researchers to contemplate reform and innovation measures for teacher education in Jordan and Turkey (Al-Amoush, Markic, Abu-Hola, & Eilks, 2011; Al-Amoush, Usak, Erdogan, Markic, & Eilks, 2013).

6 Conclusions and Implications

One of the main strengths in the use of drawings is their consequential validity (Messick, 1989), which means the power drawings contain for effecting change and improvement. Drawings are not only a powerful way to document science teachers' beliefs, concepts, and pedagogical attitudes concerning the teaching and learning of science. They also constitute a mighty tool for reflecting upon teacher education (Markic & Eilks, 2008, 2012), as well as in initiating changes in classroom practices (Haney, Russell, & Bebell, 2004). We used the described extended version of DASTT-C over many years with student teachers and teachers at various levels of their education (Markic & Eilks, 2013). In evaluating the results and reflecting them with the student teachers, the method proved to be an extremely useful tool for helping student teachers. They allow young, inexperienced educators to become more aware of their personal, initial beliefs and attitudes about teaching and learning before starting teacher education. They also allow teachers to reflect upon and change their classroom practices after having made essential steps in their teacher education. From these experiences, it is suggested that university educators and teacher trainers also benefit from such measures, since they can now inquire more deeply into the a priori beliefs which prospective teachers bring with them and also gauge the potential effects of both pedagogy seminars and internships (Markic & Eilks, 2013).

However, one careful remark also needs to be made. Weber and Mitchell (1995, p. 35) observed that drawing is "a natural form of symbolic expression" for children. However, this is not true for older children or adults. Teenagers and adults often think that they cannot, do not want to, or never will be any good at drawing. Therefore, they often refuse to participate in activities requiring drawing or sketching. Interestingly enough, this may also be a somewhat culturally specific phenomenon. Deguchi (1998) and Winner (1989) discussed the fact that in countries like China and Japan, drawing seems to be a more universally maintained and valued skill than it is, for example, in the United States. However, if methods based on drawing are sufficiently explained, justified, and used anonymously in evaluative situations, our experience has shown us that most chemistry teachers and student teachers in our case studies and seminars were quite open to trying out the testing tools presented. If applied correctly, drawings can provide a rich source of information for research, assessment, and self-reflection purposes when it comes to exploring chemistry teachers' educational beliefs and attitudes.

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Chemistry Teachers' Attitudes and Needs When Dealing with Linguistic Heterogeneity in the Classroom

Silvija Markic

Abstract Though language and chemistry are seen as two extremes on a spectrum, language is still one of the central mediators of any learning process. To show the importance of language and linguistic skills, the chapter will discuss the role of linguistic issues for learning in general and of chemistry education in particular from different points of view. Finally, to sum everything up and since the teachers are a key factor for changing the situation in schools, the chapter will list the attitudes and perceptions that chemistry teachers hold when it comes to dealing with linguistic heterogeneity in the classroom. Some examples of good practice for teachers' professional development will be given.

1 The Importance of Language in Chemistry Education

It is not possible for humans to imagine a world without language. People need language—quite independent of whichever language it may be—for communication purposes and to express personal ideas, wishes, knowledge, needs and feelings. Furthermore, language helps us to think, to understand, to communicate and to express all kinds of information and thoughts. This is especially the case when we are dealing with teaching and learning in a school setting. Is it possible to imagine school—in our case chemistry lessons—without language? are we as teachers able to explain the chemical bonding in the water molecule to our students without the aid of language? Can we even think without employing language? In most cases, the average person will answer these questions with a resounding "No!" Language is a central aspect of any teaching and learning process taking place in a school setting in general and in chemistry classrooms in particular. Furthermore, school lessons largely occur at the linguistic level most of the time, quite independently of the kind of lesson: student-centred work phases, teacher-centred experiments, presentations, experiments, etc. Thus, all teaching and learning activities are primarily based on language, regardless of whether they are written or oral in nature. Many

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activities take place in the classroom including reading, writing and listening just to name a few, which all include the use of language. All students in public school systems require a basic understanding of a given culture's official language, its rules, its usage and its often tricky and changeable nature in order to learn. For example, during problem-solving exercises students read and write using language. Written language is deciphered in order to read the text, before spoken language is used to communicate the pathway taken from the initial position to the learning goal (Lemke, 1989).

It seems quite self-evident that if a student's language skills, particularly those for reading and writing, are poor or even deficient, the learner will face severe difficulties and disadvantages in learning any new content in chemistry. The situation can be exacerbated if the student possesses only a limited vocabulary. Even excellent learners can experience major difficulties in the chemistry classroom, considering the fact that various disciplines in the natural sciences themselves and their accompanying jargon effectively represent "foreign languages" to the layman. This conclusion becomes even more obvious if we think about the sheer amount of reading and writing occurring in the average chemistry classroom: reading textbook chapters, solving worksheets, understanding PowerPoint slides, taking tests and quizzes, writing up laboratory reports and protocols, taking notes during class, answering homework questions, etc.

The above-mentioned problems will be even worse for someone whose mother tongue differs from the official language of the country where she/he studies, since that person is effectively being instructed in complicated subject matter covering a wide range of school subjects in a foreign language. Students being taught in a second language they have not yet mastered may not understand even simple words or terms, let alone entire sentences, questions or complicated instructions. For example, in Germany it is quite common to meet children in schools—especially in large urban areas—with migration backgrounds. One in five people living in Germany fits this pattern. A total of 10 % of Germany's residents are literally citizens of foreign nations, with Turkish, Russian, Polish, ex-Yugoslavian dialects, Greek and Italian being some of the most common languages. Often children speak one (or even two) non-German language at home and learn German as a foreign language in school and in public settings. Additionally, they are expected to learn English as a lingua franca in school (and quite possibly one or two other foreign languages if they wish to study at the university). German (native) students on the other hand generally tend to be monolingual until they leave primary school.

Both science and chemistry education in the past have quite often understood language as a simple tool for the transfer of information from one person to another (Fang, 2006; Ford & Peat, 1988). Unfortunately, we know from the history of education that language was mostly considered to play a rather passive role with low levels of influence on students' learning processes in the chemistry classroom. Rollnick (2000) stated that decisions concerning the use of language in the classroom are usually not based on findings related to best practices in education but more often cater to political expediency than educational effectiveness. However, the idea of the passive role of language in learning has drastically changed in the last few decades. Research on the influence of language in teaching and learning has gained strength in the interim with some quite interesting results on this topic being published. These have highlighted the crucial role which language plays in the teaching and learning of chemistry. Today language is increasingly considered to be one of the dominating factors which can either foster or hinder the learning of chemistry as a discipline. Chemistry researchers and educators have become more aware that language and the personal, linguistic skill of students are intimately intertwined with the effective, motivated learning of chemistry topics in schools. The studies by Lee and Fradd (1998) and Lee (2005) showed that poor linguistic skills can result in difficulty with asking pertinent questions, an uncertainty when investigating phenomena and insecurity which leads to summarising experimental results in "school language" instead of scientific language. This can seriously destroy student motivation when it comes to both participating in chemistry lessons and learning about important chemistry phenomena and content knowledge.

We can recognise language as a negotiating process for learning in general. This also applies to the specific case of chemistry lessons (Grabe & Stoller, 1997). Effective communication and critical-thinking skills in the chemistry classroom are two of the primary goals which have been stressed by national German educational authorities. Thus, promoting general language skills and the specific terminology of the scientific community remains one of the main objectives of chemistry teaching. Students need to explicitly learn scientific language with all its technical terms, formulae and patterns of argumentation. If scientific language causes increasing difficulties for learners in the classroom, it will also result in higher numbers of learning problems, increasing levels of misunderstanding and spiralling levels of demotivated students. In order to understand and master scientific language, students must first master and possess sufficient knowledge of the primary language spoken in the country where they are living. Furthermore, the subject-specific language of chemistry is necessary, if one wishes to deepen one's overall understanding of chemistry. On the other hand, knowledge of scientific language also entails a shared understanding of the subject-matter content (Brown & Ryoo, 2008). Last but not the least, content knowledge in chemistry will allow students not just to be able to communicate in the scientific community but also in society at large when it comes to participating in societal debates on socio-scientific issues (e.g. climate change, sustainability, renewable energy resources, etc.).

There is also another justification which supports the statements above. Ever since the 1990s, *scientific literacy* for all citizens has become a widely accepted and popularised goal for formal science teaching at the primary and secondary school level (e.g. AAAS 1993; KMK 2005; NRC 1996; UK government 2010). According to the concept of *scientific literacy*, students at school should be able to communicate with wide-ranging partners and be able to participate in public and open discussions dealing with scientific, technological, social and ecological topics. In achieving this aim, it is important that in chemistry, lessons emphasise the importance of language and linguistic competencies in and for learners. With scientific literacy in mind, Wellington and Osborne (2001) declared that comprehending and being able to use the scientific language is an essential component of successfully mastering the natural sciences. It is important that each student is able to understand and explain the fundamental concepts of chemistry in clear, unequivocating language. Phillips and Norris (1999) and Norris and Phillips (2003) also mention the specific ability to infer meaning from a text, including the capability of employing information rationally during discourse or decision-making in science-related, personal and social issues, as one of the main features of scientific literacy. In this regard, it is important that chemistry lessons explicitly and directly emphasise both language and students' linguistic competencies. Scherz, Spector-Levy, and Eylon (2005) investigated the impact which explicit instruction of literacy and communication abilities in middle-school science lessons can have. Their approach included information retrieval techniques, scientific reading measures, listening and observing tips, scientific writing practice, information representation exercises and knowledge presentation skill development. Their conclusion was that significant improvements could be observed in the intervention group for some of the communication skills mentioned above, when this group was compared with the control group, in which no explicit instruction of communication and literacy skills had taken place.

There are many different approaches for assessing scientific literacy. Some researchers concentrated on the reader's ability to construct valid arguments based on evidence taken from the text (Duschl & Osborne, 2002; Norris & Phillips, 2003; Phillips & Norris, 1999; Wandersee, 1988). Others measured the ability of the reader to raise additional questions based on what the material read, including searching for further information necessary to answer their questions (Hofstein, Navon, & Mamlok-Naaman, 2005; Korpan, Bisnaz, & Bisnaz, 1997; Norris & Philips, 1994).

The correct use of scientific language and the ability to understand scientific writing are an important part of scientific literacy in the above-mentioned studies. It is impossible to be scientifically literate (able to use, understand and explain the main ideas of science or to participate in societal debates on science-related issues) without understanding and being able to adequately use language in science-related contexts. Therefore, in addition to the above-mentioned test, one test for scientific literacy might be the ability to read and comprehend science-related articles in newspapers (Bybee, 1997). What exactly remains after a person's school education is over? Trying to count how many specialists or "unusual" words appear in a single science article or in a practical task can serve as a good example (Johnstone & Wham, 1982). The results show that this problem worsens as the expected scientific literacy of the audience increases. Science textbooks and articles in scientific journals require a higher reading ability than that necessary to understand normal prose such as that found in widely available, best-selling novels or magazines. When structuring chemistry lessons, this means that the pedagogical strategies chosen by teachers should not only take account of the students' foreknowledge and skills in speaking, reading and writing but also need to centre all learning efforts on the use of scientific language.

A strong separation between language skills and science is widespread thinking. In schools not just the students but also a majority of both language and science teachers view language and chemistry/science lessons as independent entities. Furthermore, they don't recognise the connection between language skills and chemistry learning. Some teachers have even accepted the faulty, stereotypical idea that people who are good in chemistry or science in general tend to be bad in (foreign) language classes and vice versa. However, several new studies in chemistry education have underscored that a close connection between language skills and science learning does exist (Lee & Fradd, 1998; Lee, 2005).

Modern theories of learning tell us that all learning processes in the classroom can be understood as processes of information exchange and knowledge mediation (Vygotsky, 1978). Furthermore, the information found in the classroom is not simply supposed to be exchanged but should also be captured in written form. In chemistry lessons students are required to express their ideas, explain their observations and debate the theories behind the experiments. All of these classroom actions fall under a communication process which requires language skills. This means that a very strong link exists between the issues of information and knowledge, students' personal linguistic skills and the careful selection and usage of language and scientific language (Cassels & Johnstone, 1984).

In addition, constructivism represents the basic theory which is currently behind the consideration of the role language plays in learning. Currently, constructivism is the most commonly embraced learning theory in both modern education and chemistry education (Bodner, 1986). Learning is an active process by the student, who seeks to capture new information and connect it with pre-existing knowledge structures in the mind. This process can only happen through the use of language. Constructivism has also revealed that knowledge cannot simply be transferred from one mind to another. Any information which is captured undergoes changes in the mind of the new learner before it is stored. This can only occur through thought in the form of either words or graphic representations. However, both of these are linked to normal or scientific language.

Research indicates that significant differences exist in the daily, informal language employed by young children and adolescents. Such informal language also includes the academic language typically found only in schoolroom situations, including the subject-specific language and jargon used in the natural sciences. Scientific language in school lessons also possesses unique characteristics which directly impact the learning effectiveness and the quality of discourse in science classes (Snow, 2010; Yore & Treagust, 2006). Therefore, there is a clear need to integrate language-based learning into chemistry lessons (August & Hakuta, 1997; Chamot & O'Malley, 1994; Lee & Fradd, 1998). Natural science classrooms in general and chemistry in particular can serve as a platform for promoting the acquisition of a language, but language classrooms cannot serve the same function when it comes to learning scientific language (Casteel & Isom, 1994; Stoddart, Pinal, Latzke, & Canaday, 2002).

2 Language and Linguistically Heterogeneous Classes

In many countries, multilingualism is a necessary requirement for today's global business world and community. Ironically enough, multilingualism in school contexts—especially in the Western world—is often viewed as a potential source of learning deficits and problems. In the 1990s Aikenhead (1997) researched linguistic issues in the specific case of Native Americans, including the positive and negative consequences which the demand for multilingualism had on their education. The recent TIMSS and PISA studies have also moved students' linguistic abilities into the political and educational spotlight, especially in regard to the disturbing link between a person's social class, language skills and overall chances for educational success, a situation which is also valid in the field of chemistry education (Lynch, 2001).

In many cases of multilingualism, which quite often takes the form of bilingualism or semi-bilingualism, the ability to speak several languages can actually become a disadvantage in educational settings (Pollnick & Rutherford, 1993; Johnstone & Selepeng, 2001). Such disadvantages are usually linked to the migration background of many students and their parents, who generally have not yet mastered the language of their new country. This inability of migrant parents to support the learning efforts of their children in a foreign language may also be exacerbated by low levels of parental education due to conditions in the home country and/or an apathetic view at home regarding education and its overall importance. As a result these students tend to achieve much lower levels of linguistic competence in the country's official language than is the national norm. Learners are effectively barred from attaining higher levels of education such as university when compared to native speakers (Lee, 2001). Additionally, not all migrant languages are equally (dis)advantageous. Germany serves as a good example of this. Turkish, Russian and Polish are quite often offered as official school subjects in Germany, especially in larger urban areas with sizable minority language populations. Students speaking these languages not only receive explicit and intense education in their mother tongue but also quite often get extra help in the form of "German as a foreign language" classes. As speakers of minority languages taught in school, they can drop the second foreign language after English, which the school system requires for entry into university. They can be officially tested orally and in written form in their first language to cover all language requirements. Other students who speak less-widely disseminated, less prestigious, non-European languages such as Tamil, Arabic, Urdu, Korean, etc. do not reap these advantages. Their mother tongue is never explicitly taught to them in any setting, and they face the unenviable task of learning German as a foreign language while meeting all of the OECD's and European Union's "2 + 1" foreign language requirements if they ever wish to study at a German university.

However, it must also be stated that the issue of linguistic heterogeneity is not exclusively a migration issue. It has been found with increasing frequency that native-speaker students often have less-developed language abilities than immigrants in many countries (e.g. Cassels & Johnstone, 1983; Johnstone & Selepeng, 2001). The reasons for this may stem from the special needs of some learners. Problematic familial or social backgrounds can lead to lower levels of linguistic abilities. This in turn, according to studies such as PISA, can directly influence a student's realistic learning success in any domain of school education.

3 The Language of Chemistry and Its Characteristics

As mentioned above, chemists do not only speak the official language of the country where they live. They can also effectively use the scientific language and jargon of chemistry. Knowledge and understanding of scientific language is an absolutely necessary factor for understanding chemistry as a subject (Hodson & Hodson, 1998). For most students, scientific language represents a new, foreign-seeming language. Scientific terminology differs drastically from everyday, often sloppy language use, including the language students frequently employ in other school subjects. Learners quickly realise that scientific explanations are demanding and precise and have very little "wiggle room". A good example of this is the difference between the terms "weight", which is gravity dependent, and "mass", which does not depend on gravitational pull. Consternation is quite often the result when learners discover that an astronaut always possesses the same mass on Earth, on the moon and in space but weighs 100 kg, 16 kg and effectively 0 kg in these three environments due to gravity. While it is common to think that science in general and chemistry in particular are less dependent on language or culture than literature or the social sciences are, there are still many reasons to focus on linguistic abilities when teaching chemistry. Many teachers and students compare the learning of scientific terminology in chemistry to learning a foreign language (Childs & O'Farrell, 2003). But learning a second language usually means learning a new word for a phenomenon which is already known in a learner's mother tongue. Learning scientific terminology is actually more similar to acquiring new vocabulary lists, for example, memorising the names of laboratory equipment. Even so, when it comes to learning and using additional vocabulary which is connected to the concepts underlying a subject, most learners consider the process to be difficult and somewhat painful. They are not required only to learn to learn vocabulary and the accompanying semantics but must also develop an understanding of the phenomena themselves and the theoretical concepts behind the terms. Scientific language also proves itself to be difficult for most students in chemistry classes. They often struggle to simultaneously understand the phenomena they have just discovered while being expected to automatically and properly employ the correct scientific language to describe what they have learned at a high level of professionalism (Johnstone & Wham, 1982). Such explanations are not only connected to the latest scientific vocabulary the students have just acquired but also to vocabulary and other phenomena which were covered in past lessons. But students require a significant amount of time and effort to learn the scientific language of chemistry and become fluent in it, just as small children need long periods of time in order to learn to ride a bicycle. Finally, the scientific language used by chemists differs in many details to the everyday language students speak. Some examples (e.g. Markic, Broggy, & Childs, 2013) include:

- Different meanings represented by the same word in chemistry classes and everyday life, e.g. solution, neutralisation (Schmidt, 1991), force, energy, attraction, heat and temperature, mixing and mixtures and weight and mass.
- Different correct meanings exist for the same concept, e.g. oxidation or matter.
- The relatively large number of unique, professional terms in scientific language can lead to cognitive overload among students.
- Written scientific language is often paralleled by symbolic forms, e.g. symbols for the elements or drawing chemical formulas and chemical equations instead of using normal words and sentences.
- The high use of graphs and diagrams to depict and highlight the scientific meaning of data.
- Employing forms of specific, logical argumentation in scientific discussions and writing such as laboratory reports, etc.
- The grammar requirements of scientific language like the specific use of either the present or future tense of a verb to describe something.
- Many words sound very similar to each other and are difficult to differentiate between, especially for beginners (alkanes, alkenes, alkynes).
- Most science textbooks use expository language. The text is informative and presents large amounts of factual scientific content (Norris & Philips, 1994). Scientific sentences are much shorter than most sentences in everyday sources but carry an enormous abundance of content. The sentences are simple, short and loaded with information.

New standards are calling for science to be taught as inquiry. However, this approach may also frustrate students with different cultural and linguistic backgrounds. This is because they often lack sufficient language skills and are unfamiliar with asking effective questions, investigating and reporting upon results using scientific language (Lee, 2005). Please think about how would you feel being in a new country, maybe not knowing any person in your class and having the teacher taking to you in some "funny" language? You also see that the teacher is writing something on the blackboard that could be important, but you don't know what to study for a test. Those students do not only feel frustrated but may also lose interest in and the will to study chemistry; they don't see the importance of the subject anymore for either their school or everyday lives.

In such classes it is obvious that the students are losing enthusiasm for chemistry and chemistry lessons. Many teachers think that doing hands-on experiments will recapture students' enthusiasm and increase their motivation for the subject. However, Cassels and Johnstone (1984) showed that students' use (and need) of scientific language is highest during experiments. Thus, doing more experiments in language-heterogeneous classes could cause non-native language speakers to become even more demotivated: the opposite of what teacher was attending to do.

Thinking about those students, the normal reaction is also that they become more insecure in their language and they withdraw. Their self-confidence and their self-assurance decrease. Outwardly, those students are mainly quiet and not noticeable in the classroom. Therefore, most teachers feel like the students understand the concepts being taught in the classroom and that they don't have any questions at all. Accordingly, teachers don't see the need to help those students.

4 Linguistic Issues from Teachers' Perspective

Teachers are seen as one of the key factors for changing lessons, methodology and teaching practices (Ernest, 1989; Hattie, 2009). Ever since the 1980s, researchers have known the importance of both teachers' beliefs and their perceptions when it comes to positively influencing and helping to carry out educational reform (Nespor, 1987). This is also true for chemistry teachers' perceptions of and beliefs about language and linguistic issues in the chemistry classroom. There has not been much research published in this area to date, and that which does exist comes mainly from American researchers. However, the findings of this research are similar in many of these studies.

Riebling and Bolte (2008) concluded in a study of German teachers that chemistry educators need to be extremely cognisant of and sensitive to possible linguistic problems in their classrooms, in order to identify such issues correctly and handle them properly. Benholz and Iordanidou (2004) found that this is especially difficult for teachers who are monolingual themselves. Identifying linguistic deficits in their students becomes very hard in such cases, with the general outcome being that lessons are prepared solely to address monolingual students. In her study of language as a gatekeeper to learning, teaching and professional development, Moore (2007) interviewed three Native American teachers in a period of five months. One of the participants stated that language does have an influence on students' grades. This teacher also mentioned that students often have difficulties in language use and selection of proper writing style. They feel as if they are being graded unfairly and often achieve failing marks on standardised tests. However, the same teacher noted the reason he understood this was the fact that he had experienced the same thing during his time as a schoolboy. All of the teachers in Moore's study (2007) viewed language as a barrier for students to learn and understand science. One teacher said that teaching is a challenge for both teachers and students. Another discussed tensions arising in the classroom due to language in the same context. This reveals similarities with some of the research data mentioned above. Chemistry teachers are generally not trained in dealing with language issues. The obvious difference, however, is that teachers themselves can be monolingual or multilingual. It appears that multilingual teachers are more sensitive to the language and linguistic difficulties of their students. Possibly, this is because many of them have had similar experiences during their time at school or because learning foreign languages in school and at university has made them more sensitive to the intricacies and pitfalls involved in language and communication.

Most research on student literacy among non-native speakers in science classes has been conducted at elementary schools (Lee, 2005) and almost always concentrates on English Language Learners (ELL). Little research has been performed at the high school level as of yet. Because of this fact, it is difficult to pinpoint studies which are primarily focused on chemistry teaching. However, the similarities between general language and scientific language in natural science classes are obvious. Lee, Maaerten-Rivera, Buxton, Penfield, and Secada (2009) found that teachers in elementary schools were generally knowledgeable about science topics at their specific grade level and that they taught science to promote student skills in understanding and inquiry. However, elementary teachers rarely discussed student diversity in their own teaching with other colleagues at their schools. Cho and McDonnough (2009) found that ELL teachers for science in general and chemistry in particular mentioned the language barrier as their greatest challenge. In other groups that are not defined explicitly as language learners, such as students from homes that speak other languages then the official language, this may also be a barrier. However, in such cases science teachers would probably not even be aware of this as a source of difficulty in studying science. Lee et al. (2009) showed in their study that teachers do pay attention to linguistic issues among their students, but they tend to do so quite randomly. Additionally, the teachers in this study allowed students to use their mother tongues in the classroom. Furthermore, Verplaetse (1998) found that teachers tended to interact differently with ELL and native English-speaking students. Educators tend to speak more slowly with non-native speakers, use simpler words and tell students exactly what to do rather than asking questions. When these teachers did employ questions, they used simple yes-or-no questions instead of asking for answers which demanded high-level thinking capabilities. As a result of this, ELL students were given very limited opportunities to engage in science and chemistry discourse, thus decreasing their chances to construct their own knowledge. One explanation could be that science teachers in general don't feel responsible for teaching language in their classes and simply assume that all students are capable, efficient users of the official language (Tajmel, 2010). Chemistry teachers at the middle and high school levels are often unaware of linguistic issues and do not view *teaching for diversity* as their personal responsibility. Other studies reveal diversity in the classroom often slips in under the radar screen, since many educators simply accept it as a given variable (e.g. Bryan & Atwater, 2002). The same holds true for elementary school teachers (Bryan & Atwater, 2002), who along with secondary school chemistry teachers presuppose that ELL students must first acquire English before learning chemistry. Thus, educators are largely unaware of the linguistic and cultural influences on science learning, a situation which is made worse when they purposely overlook linguistic differences and accept inequities as a given.

As already mentioned, science in general and chemistry in particular and language in schools are often perceived as the two ends of a spectrum by students and teachers alike (Moore, 2007). This may be linked to perceptions of the hard sciences and the humanities representing nonoverlapping magisteria. It would appear that chemistry teachers are often not sensitive enough to recognise the linguistic difficulties their students have and don't feel competent in or responsible for dealing with linguistic issues. It is also the case that many teachers lack strategies for dealing with such problems in their chemistry classes. A not infrequent opinion which researchers constantly hear from teachers is that the severe time shortages built into the chemistry curriculum are a good reason not to deal with linguistic heterogeneity and its attendant difficulties (Cho & McDonnough, 2009).

In their study of 221 teachers of science (including chemistry), Lee et al. (2009) evaluated teachers' perception of teaching science to ELL students. The study revealed that teachers rarely participate in professional development activities dealing with language and linguistic difficulties in science class. Over half of the teachers took additional coursework at the university level, and only 10 % had not had teacher training experience for language and science. In other countries coursework offers on this topic also remain rare for in-service training opportunities. Although the majority of teachers in Lee et al.'s (2009) study stated that they had attended courses dealing with linguistic heterogeneity, they went on to state that they had used the acquired strategies primarily to promote English language development in only a tiny number of science lessons. They had also elected to allow the use of ELL students' native languages in a few lessons.

When it comes to organisational support, Lee et al. (2009) stated that science teachers are generally supported by their principals and that they often collaborate with other teachers at their school. However, collaboration normally entails sharing teaching materials and activities, dividing up assessment tasks, comparing students' work or swapping stories about teaching experiences with their co-workers. During such meetings they only rarely discuss the problems of heterogeneity and diversity on their classes, for example, issues of ELL students.

Teachers tend to view students' poor skills in reading, writing and mathematics as moderate barriers to most science teaching and learning. Furthermore, Lee et al. (2009) also identified school-level constraints, parents, family and community as other moderate barriers. A quantitative research study of 33 teachers carried out by Cho and McDonnough (2009) revealed that the language barriers and ELL students' lack of foundational science knowledge represented the largest challenges to educators.

Teachers in Cho and McDonnough's (2009) study selected different strategies for dealing with the above-named challenges. The most prevalent accommodation made by the teachers was giving ELL students additional time to complete assigned tasks. More than a half of the participants stated that they always (or quite often) provide ELL students with extra time to complete basic tasks. The second most popular strategy was slowing down the teachers' rate of speaking to aid in understanding, followed closely by the strategy of grouping ELL students together so that they can help one another. It is interesting to note that alternatives like providing different tasks and assignments, substituting differentiated instructional materials or using other grading/assessing methods were the least-adopted accommodations on the list, occurring rarely or never. One explanation mentioned by Cho and

McDonnough (2009) for the lack of supplementary teaching materials in ELL classrooms is the lack of school resources actually available to teachers. Another reason for lacking accommodation in these areas may be that teachers don't know how to properly adjust their instruction, instructional materials, assignments and tasks for ELL students. The participants also reported that they rarely graded ELL students any differently from other students. Nor did they directly consult with ELL teachers to address linguistic heterogeneity. This last aspect is quite surprising, considering that ELL teachers are often in-house experts in many schools but tend to be quite generally ignored by their colleagues. The very limited use of accommodation strategies and tools found in this study must lead us to the conclusion that a pressing need for targeted professional development exists in much of the educational world.

Teachers thought that having appropriate instructional materials and pedagogical training were the most necessary tools for successfully dealing with linguistic heterogeneity in their science lessons. When science teachers were asked by Cho and McDonnough (2009) which type of support they would like to receive, a majority of them named bilingual instructional materials as important or very important. It is interesting to mention that using bilingual materials does make more sense than providing teaching materials solely in students' first language. The bilingual approach does not take students' opportunities to interact and learn in the chemistry classroom away. Instead the learners are challenged in their own language, supported in the learning of their second language and receive an unparalleled chance to link both languages and the content matter in their memories.

The second thing chemistry teachers wished for is professional development training. In contrast to Lee et al. (2009), both Reeves (2004) and Penfield (1987) found that content-area teachers—a term which also includes chemistry educators—had received almost no training in dealing with linguistically heterogeneous classes. Different studies on professional development programmes have made it clear that such programmes should be directly tied to teachers' needs, wishes and interests. One further factor which must be taken into consideration is teachers' a priori knowledge of a given topic. The majority of teachers interviewed by Cho and McDonnough (2009) wished to be trained in ELL instructional strategies. They viewed this as very important. Additionally, over half of the teachers in the same study also rated training in second language development and in learner variables as very important. This is linked to an interest in assessing and grading ELL students in chemistry classes. Furthermore, Buxton, Lee, and Santau (2008) stated that special professional development is needed in the areas of curriculum materials and workshops. These two aspects can complement and reinforce each with regard to improving teachers' knowledge, beliefs and practices in science instruction and to English language development for ELL students.

5 Conclusions

Although lacking linguistic skills may represent one of the major factors hindering students when learning chemistry, this factor is also the one which teachers most often ignore as irrelevant for their learning group or take for granted when planning their lessons. Because of the reasons listed in the previous sections, a chemistry teacher must be aware that every educator in every school subject has an influence on the development of students' linguistic skills to differing degrees and in different areas. Each chemistry teacher must finally realise that there is no dichotomy between language and chemistry when it comes to understanding new information. All school subjects interact with the overall development of students' general language abilities. Thus, chemistry teachers carry the additional responsibility of acquainting their students with an additional, scientific language as well. This is also a crucial factor in preparing students for further education, not just in chemistry but for lifelong learning. It also allows young people to express themselves clearly and concisely and to actively participate in societal debates dealing with issues that affect not just the learners but all the people around them as well.

Thus, there is a high need of making both chemistry student teachers and in-service chemistry teachers aware of the linguistic issues in their classes. Furthermore, we should pay more attention in our pre- and in-service chemistry teachers training on making (student) teachers sensitive for the linguistic heterogeneity in their classroom and change their attitude and beliefs concerning this topic. One possible method to sensitise (student) teachers to the linguistic challenges their students face is to ask them to write a laboratory report in a second language they studied in school. Usually the student teachers do not have sufficient capacity in the second language to do so, even if they are describing a simple experiment, like a filtration. This experience puts the (student) teachers in the same situation as some of their students. Additionally, (student) teachers could be shown examples from everyday school lessons that could be potentially confusing to students who are non-native speakers or who do not have strong native language skills classes (see Fig. 1). Finally different methods about how to deal and teach in linguistic heterogeneous classes must be given. An overview of the methods is given in Markic et al. (2013).

Furthermore, for change to support learning in a linguistically heterogeneous classroom, there must be collaboration between all teachers in schools, especially those who are resistant to change and new methods (Gamoran et al., 2003). The school programme and organisation are an important factor in this context. In schools with a strong academic focus and an orientation on student-centred teaching, the differences in student performance are much less dependent on students' possible migration backgrounds than in other schools (Lee & Smith, 1995). Science teachers in general and chemistry teachers in particular in these types of schools tend to work more in professional collectives than as autonomous individuals. Such collective work positively affects the quality of science teaching (Lee, Smith, Croninger, & Robert, 1997). Some typical characteristics of such team-oriented

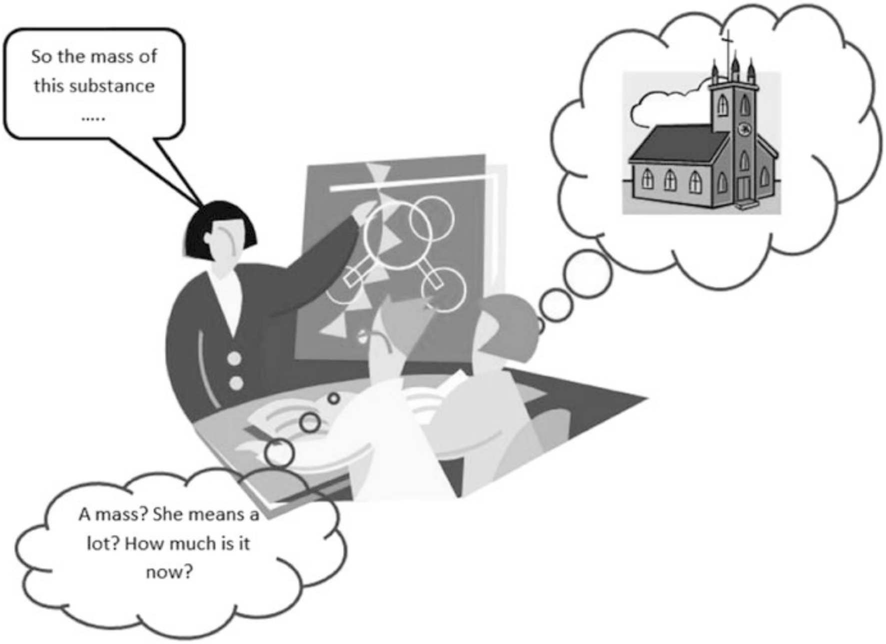

Fig. 1 Example from a school lesson

collectives include the widespread cooperation among science colleagues, the cooperative development of ideas and materials, plus the standardisation and unified following of the same teaching and learning goals (Lee & Smith, 1995). Markic (2011, 2012) concluded that cooperation between chemistry teachers and German as a second language (GSL) teachers can offer good opportunities for developing new teaching materials which address the linguistic heterogeneity found in most modern chemistry lessons. This project has shown the benefits of collaborative development of chemistry lesson plans by chemistry teachers and GSL teachers. The approach seems have the potential to create motivating and attractive learning environments which allow teachers to simultaneously help students learn chemistry subject matter while also improving the learners' knowledge of and competency in the German language. The study by Pawan and Ortloof (2011) also showed that collaboration between English as a second language (ESL) and content-area teachers is possible. Furthermore, the researchers listed information about the key actors, opportunities, tensions and conflicts in the collaboration between the two sets of teachers. The researchers found that a number of interactional and organisational barriers need to be taken into account when collaborating with different groups of teachers. However, these obstacles seem not to be insurmountable.

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Majors' Gender-Based Affective States Toward Learning Physical Chemistry

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Abstract This study examines the affective states of students who are chemistry majors at the junior and senior levels, in the context of a Physical Chemistry II (PChem II) course. The study relies on students' self-reflections while they respond to an online survey system. The online survey includes three sections: demographics, Reformed Teaching Observation Protocol (RTOP), and Modified Fennema-Sherman Mathematics Attitudes Scales (mFSMAS). The RTOP instrument is used by the students to describe the teaching in the PChem II class. The mFSMAS was chosen to measure attitudes from the gender differences point of view. Internal consistency analyses indicate that the instruments are reliable. The findings reveal that females do not perceive themselves as being disadvantaged when it comes to learning PChem II topics. The same conclusion is valid for their male counterparts. In addition, RTOP, as rated by students, describes the nature of the PChem II as traditional, lecture-based instruction. A significant correlation coefficient between the composite scores of RTOP and mFSMAS indicates that the use of inquiry-based teaching strategies correlates to positive student affective states toward learning physical chemistry. Accordingly, in the case of the specific PChem II course examined in this study, the dominance of lecturing led to low to moderate positive attitudes toward the course.

Keywords Physical chemistry education • Affective states • Fennema-Sherman scales • Reformed teaching observation protocol • Gender differences

1 Introduction

Over the last 20 years, there has been a decrease in young people's interest in science-related fields, particularly among girls.

> Recent work by the OECD indicates that over the last decade, in many European countries, the number of young people entering universities is increasing but they are choosing study fields other than science and in consequence the proportion of young people studying science is decreasing. Moreover, in certain key areas such as mathematics and physical

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> sciences—areas that are at the heart of sustainable socio-economic development—even the absolute number of students is falling in some countries. Indeed, some universities in Europe are reporting a halving in the number of students enrolled in physics since 1995.
>
> When looked at from a gender perspective the problem is even worse as, in general, girls are less interested in science education than boys. As shown by the OECD Programme for International Student Assessment (PISA) study, at 15 years old, there is already a strongly gendered pattern and in most countries females are significantly less interested in mathematics than males. This pattern of gender differences continues with women choosing fewer academic studies in math, science and technology (MST). In fact, at the European level, girls account only for 31 % of MST graduates (Rocard et al., 2007, p. 7).

As clearly stated, the status quo will not meet the future society needs of society with regard to advancements in science and technology. This alerts us, *the chemistry educators*, to track and detect the perceptions of students encountering various core chemistry courses as majors. Findings of these types of studies may lead to a change in the way we teach majors at the undergraduate level so that we might better support their interest in chemistry, their future learning in graduate courses in chemistry, and their entry into science-related careers.

2 Conceptual Framework

When it comes to practice of science teaching, teachers' epistemological theories affect classroom tasks and pedagogical practices. The classroom tasks and teaching practices have an impact on students' affective states toward learning science. All of these artifacts are modeled under the umbrella of epistemology.

Epistemology refers to the nature and justification of human knowledge (Hofer, 2001). Studies about epistemology have been developed with different names in literature—epistemological beliefs (Jehng, Johnson, & Anderson, 1993; Kardash & Howell, 2000; Schommer Aikins, Duell, & Hutter, 2005), reflective judgment (King & Kitchener, 1994; Kitchener, Lynch, Fischer, & Wood, 1993), ways of knowing (Belenky, Clinchy, Goldberger, & Tarule, 1986; Clinchy, 1995), epistemological reflection (Baxter Magolda, 1999), epistemological theories (Hofer, 2001, 2008, 2010), and epistemic beliefs (Bendixen, Schraw, & Dunkle, 1998). Figure 1 models how personal epistemological beliefs affect the classroom teaching. Teachers bring epistemological beliefs along with connected pedagogical practices to classroom. Students arrive in the classroom with existing epistemological beliefs and theories that lead to interpretations of instruction.

In time, students' beliefs change and so their interpretations. The outputs of these dynamic constructs affect student motivation and strategy selection. Learning occurs in conjunction with motivation and strategy selection. Thus, according to this model, motivation as an affective state is a key variable to understanding student learning better. In the section that follows, we will provide a working model of motivational categories and then focus on motivation to learn science.

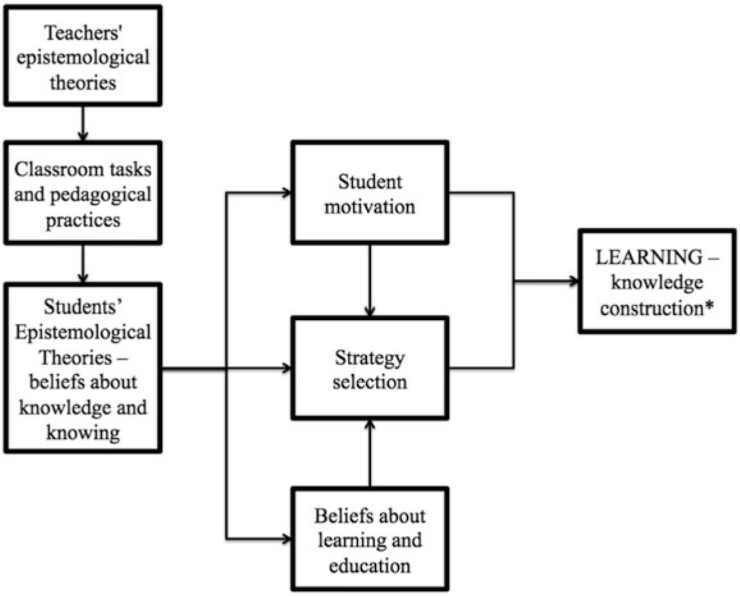

Fig. 1 A modified working model of how epistemological theories influence classroom learning. Adapted from Hofer (2001). The modification from the original model is marked with an *asterisk*, which denotes that "knowledge construction" was replaced with "knowledge acquisition and transformation." Motivation and beliefs in this model are the linkages to students' affective states toward learning science

2.1 Motivation to Learn Science

Relevant literature about motivation to learn is often studied with other variables—for example, how beliefs of self-efficacy can enhance or damage performance through their effects on cognitive, affective, or motivational processes (Bandura, 1986; Bandura & Wood, 1989). Adelman (1978) notes that since cognitive and affective processes are primary determiners of behavior, an understanding of the relationship of these processes to learning requires an understanding of the construct motivation in general, as well as an understanding of how to promote and sustain motivation. In other words, motivational dimensions (i.e., factors or variables from a measurement point of view) within instructional settings should be theoretically clarified for further meaningful investigations.

Keller (1987) defines four factors that promote and sustain motivation, which are known as "motivational categories": **a**ttention, **r**elevance, **c**onfidence, and **s**atisfaction (the **ARCS** model). Each of these four factors is composed of three sub-concepts, described below. Additionally, there is a relatively recent Web site about the ARCS model for further details (see Keller, 2006).

1. Attention
   (a) Perceptual Arousal: Create curiosity and wonderment by using novel approaches and injecting personal and/or emotional material.
   (b) Inquiry Arousal: Increase curiosity by asking questions, creating paradoxes, generating inquiry, and nurturing thinking challenges.
   (c) Variability: Sustain interest with variations in presentation style, concrete analogies, human-interest examples, and unexpected events.
2. Relevance
   (a) Goal Orientation: Provide statements or examples of the utility of the instruction, and either present goals or have learners define them.
   (b) Motive Matching: Make instruction responsive to learner motives and values by providing personal achievement opportunities, cooperative activities, leadership responsibilities, and positive role models.
   (c) Familiarity: Make the materials and concepts familiar by providing concrete examples and analogies related to the learners' work.
3. Confidence
   (a) Learning Requirements: Establish trust and positive expectations by explaining the requirements for success and the evaluative criteria.
   (b) Success Opportunities: Increase belief in competence by providing many, varied, and challenging experiences which increase learning success.
   (c) Personal Control: Use techniques that offer personal control (whenever possible), and provide feedback that attributes success to personal effort.
4. Satisfaction
   (a) Natural Consequences: Provide problems, simulations, or work samples that allow students to see how they can now solve real-world problems.
   (b) Positive Consequences: Use verbal praise, real or symbolic rewards, and incentives, or let students present the results of their efforts ("show and tell") to reward success.
   (c) Equity: Make performance requirements consistent with stated expectations, and provide consistent measurement standards for all learner's tasks and accomplishments.

Although motivation can be thought of in general terms, we are more interested in a specific type of motivation: motivation to learn science. Lee and Brophy (1996) define student motivation to learn as follows:

> In summary, student motivation in the classroom is conceived in terms of students' choice of goals and strategies during task engagement. In particular, the state of motivation to learn exists when students engage in classroom tasks with the goal of understanding the content and activate strategies for developing such understanding. Further, the trait or generalized disposition of motivation to learn exists when students routinely seek to accomplish the intended academic goals, either because they enjoy and take satisfaction in learning or because they feel duty-bound to do so (pp. 304–305).

Lee and Brophy (1996) go on to describe five patterns of student motivation, specifically to learn science: (a) intrinsically motivated to learn science, (b) motivated to learn science, (c) intrinsically motivated but inconsistent, (d) unmotivated and task avoidant, and (e) negatively motivated and task resistant.

When the modified working model of how epistemological theories influence classroom learning, referring to Fig. 1, and the five patterns of student motivation to learn science by Lee and Brophy (1996) are considered mutually, it becomes clear that students' affective states play an important role on students' science learning.

So far our theoretical framework let us focus on how classroom practices correlate with student affective states. As a way of researching these latent variables, valid and reliable instruments need to be utilized to make meaningful conclusions. We intend to measure two distinct aspects labeled as students' affective states and teacher's classroom practices. In the following subheadings, we briefly introduce the instruments we used to measure these aspects.

2.2 Gender from a Measurement Perspective

When it comes to measuring gender-based perceptions, the Fennema-Sherman Mathematics Attitudes Scales (FSMAS) survey (Fennema & Sherman, 1976) has been one of the most widely cited instruments in the pedagogical domain. The complete FSMAS consists of 108 positive and negative statements (i.e., items), scored by conventional Likert scale, theoretically measuring a total of nine themes (*or* theoretical dimensions of different kinds of student perceptions): Attitude Toward Success in Mathematics Scale, Mathematics as a Male Domain Scale, Mother Scale, Mother/Father Scale, Teacher Scale, Confidence in Learning Mathematics Scale, Mathematics Anxiety Scale, Effectance Motivation Scale in Mathematics, and Mathematics Usefulness Scale.

Because of both its lengthy nature and its potential to discern students' gender-based perceptions, the FSMAS has been shortened and transformed to other disciplines, called modified versions of the FSMAS (*acronym*: mFSMAS hereafter). For example, mFSMAS has been used to investigate attitudes toward English (Stricker, Rock, & Burton, 1993), computer science (Wiebe, Williams, Yang, & Miller, 2003), chemistry (Kahveci, 2009, 2011), educational technology (Kahveci, 2010), and physical education (Lirrg, 1993). In addition, mFSMAS has been translated to other languages like Persian (Shirbagi, 2008), Irish (Mulhern & Rae, 1998), and Turkish (Kahveci, Öztekin, & Algedik, 2006).

There are numerous reports confirming the validity and reliability of the mFSMAS. For example, see the studies by Broadbooks, Elmore, and Pedersen (1981), Melancon et al. (1994), Mulhern and Rae (1998), and Kahveci (2009, 2010, 2011).

2.3 Reformed Teaching Observation Protocol

The Reformed Teaching Observation Protocol (RTOP) was developed by the Evaluation Facilitation Group (EFG) of the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT), and the reference manual was published in September 2000 (Piburn & Sawada, 2000). The instrument quantitatively measures the "reform" nature of a classroom and identifies inquiry-based science education strategies in the classroom. The original report includes an extensive evaluation of RTOP's psychometric properties. RTOP was used in this study in order to understand the nature of PChem II course through the lens of inquiry-based science education, as observed by the students.

2.4 Purpose of Current Study

Physical chemistry (PChem) is one of the core and hard-to-achieve courses in undergraduate chemistry programs. It is considered an essential course in the education and training not only of chemists but also of many other specialists. Also, the concepts, models, theories, methods, and tools of PChem are included in all chemistry courses at both secondary and tertiary levels (Tsaparlis & Finlayson, 2014).

This research was funded through a grant[1] on developing technology-supported PChem I and II course materials, which were intended to be interactive and self-study materials. The main goals of the project were (1) to develop course supplementary materials via implementation of learning objects, (2) to investigate student misconceptions on the study topics selected, and (3) to evaluate the effectiveness of the materials developed. As a descriptive approach, this study focuses on chemistry majors' gender-based attitudes toward learning physical chemistry in order to better understand students' affective states. The description of the affective states will be informative to make conclusions on the effectiveness of the aforementioned project products, to make an assessment on students' material-wise needs to learn physical chemistry, and to interpret the cognitive data collected during the project [the cognitive measurements are two-tier tests developed by the researcher in order to identify students' misconceptions, although these findings are not reported in this study].

The attitudes are described on the basis of students' self-evaluation of their affective states toward physical chemistry. We rely on students' self-reports, as they

[1] The project is entitled "Physical Chemistry Education and Learning Objects (PChemLO): An implementation and development of the materials on inquiry-based approaches at higher education" and funded by Canakkale Onsekiz Mart University Scientific Research Projects, through grant # 2011/132.

are one way of gathering data for researching latent variables such as attitudes and motivation.

Secondly, this study provides the adaptation reports of two well-known instruments (i.e., RTOP and mFSMAS) with respect to their reliability and construct validity measures. The adaptation process refers to context-based, *Physical Chemistry*, and language-based, *Turkish*, modifications.

The research questions are as follows:

1. Are there any gender-based differences between students' attitudes about learning in the Physical Chemistry II course, as measured by the mFSMAS survey?
2. Is there any correlation between RTOP and mFSMAS scales, as evidence for the construct validity of mFSMAS?

The last research question may not be obvious to the readers. For clarification, on quantitative accounts, it measures if teaching strategies are affecting student perceptions toward PChem II courses. This measure may also be interpreted as the validity measure of mFSMAS scales in this research context.

3 Method

3.1 Sample and Settings

This is a survey research ("Survey research methods in education," 1988, pp. 254–277), involving an accessible population (Fraenkel & Wallen, 2006) of students attending the chemistry department of a public university located in the northwest part of Turkey, Europe. In specific, the participants were selected from those majors who registered for the Physical Chemistry II (PChem II) class during the Spring 2012 semester. The participation in the study was entirely on a voluntary basis. There was no sample selection rule over the accessible population, and therefore, the sample is random in nature.

Because PChem II course is an upper-level chemistry course, the total number of registered students is composed of chemistry majors only. Including the repeating group of students (i.e., the ones who retake the course), roughly 75 students register for the PChem II course every year. This number is an estimation only because a considerable number of students who are repeating the course due to low performance of the previous semester do not register for the class but just take the midterm and final exams to get better grades. In fact, the attendance requirement for these students is relaxed formally.

Ultimately, the sample size for the current study is $N = 29$ (approximately 37 % of the accessible population), which includes 62 % females ($N = 18$) and 38 % males ($N = 11$). The gender distribution in the study is representative of the course population overall. The participants were gathered at a computer lab for data collection process in several sessions, based on their availability. The participants consented to participate in the study via an online survey system before beginning of the surveys. The survey analysis was kept entirely anonymous, and no information was shared with the course instructor or others at the institution.

3.2 Measures

3.2.1 The Modified Fennema-Sherman Mathematics Attitudes Scales

A modified version of the Fennema-Sherman Mathematics Attitudes Scales (FSMAS) (Fennema & Sherman, 1976) was used to describe students' gender-based attitudes toward learning PChem courses. Attitudes that include gender aspects were of interest because as mentioned earlier, there is a gender-based lack of interest toward science.

In addition to the Turkish translation, the survey items were modified so that the instrument is suitable for a chemistry education context rather than a mathematics education context. A similar approach was previously employed to measure student attitudes in the context of computer programming by Wiebe et al. (2003).

The development and implementation of mFSMAS were carried out in three steps: (1) Fennema-Sherman's Mathematics Attitudes Scale was translated to the Turkish language, and five experts in science education and the researcher worked independently at the outset and then at a consensus meeting to guide the final form of the language translation; (2) to measure students' perceptions in learning PChem II, every item was reworded in terms of "physical chemistry" instead of "mathematics," and (3) the instrument was implemented via an online survey system.

3.2.2 Reformed Teaching Observation Protocol

Two experts worked on the translation (English to Turkish) and back translation of the Reformed Teaching Observation Protocol (RTOP) (Piburn & Sawada, 2000) survey in order to gather student observations about the nature of PChem II classes. The RTOP scale focuses on "reform-based" science education, where the philosophical approach relies on constructivist approaches, often labeled as "inquiry-based" science education. Specifically, while relying on student perceptions, this survey was used to describe the classroom environment along a spectrum of traditional teaching to inquiry-based teaching.

4 Results and Discussion

4.1 Descriptive Analysis

The descriptive statistics for the mFSMAS and RTOP items are given in Appendices A and B, respectively. The item numbers correspond to their appearance in the instruments and are used in the same fashion in all relevant tables. The mean values reported in Appendices A and B are on the basis of unstandardized scores (i.e., raw scores of the Likert scales). The descriptive statistics shown on these tables are used as references for all items in order to identify the item-based distributions—whether they are close to normal distribution or not. Items within the range of ± 2.5 skewness and kurtosis values were kept for further parametric analyses. As a descriptive conclusion, mFSMAS items 22, 23, and 24 and RTOP item 8 were omitted from further analyses because these items deviate too much from the normality condition.

4.2 mFSMAS Thematic Analysis

Exploratory factor analysis (EFA) would discern the thematic patterns of mFSMAS on the basis of the sample data. However, as the sample size is limited to $N = 29$, which means the sample to variable ratio is less than 3:1 (please see Brown and Onsman 2013) for arguments on sampling adequacy for factor analysis), the data is not sufficient to run EFA. Therefore, the factorial structure of an earlier study of mFSMAS on Turkish students in the context of chemistry education is used as a reference for the analysis (Kahveci, 2009). Table 1 shows the item-based factorial categories as drawn from Kahveci (2009) and Cronbach alpha values and the standardized descriptive statistics for the current sample ($N = 29$) in the context of PChem II. There were six factors applied to this research as follows: (1) confidence in learning physical chemistry, (2) satisfaction, (3) relevance, (4) personal ability, (5) gender difference, and (6) interest.

Raw scores were transformed to standard T-scores, while categorical statistics were computed over composite T-scores. The composite T-scores are mean calculations over all items within a category. This procedure is very similar to how factor scores are calculated for every factor when the Save As Variables feature is checked in the SPSS program. The difference in factor scores produced by the EFA is that they are z-scores and calculated by the linear combination of every variable within a factor, while the linear combination is weighed by the factor loadings. T-scores, as opposed to z-scores, were preferred in this study because they are positive below the mean.

Overall, transformation of raw scores to T-scores does not affect the distribution curves of the variables of interest, and so it also does not affect the mean-based comparative analyses. In fact, the interpretation of the new scale based on T-scores

Table 1 Factorial categories, reliability, and statistics of standard composite T-scores over mFSMAS data ($N = 29$)

Item # (scale)	Cronbach alpha	Std. deviation	Skewness	Kurtosis	Item
Factor 1: confidence in learning physical chemistry					
2 (C1+)	0.892	7.785	1.171	1.632	Generally I have felt secure about attempting physical chemistry (*Fizikokimya problemleriyle karşılaştığımda kendimi güvende hissediyorum*)
3 (C2+)					I am sure I could do advanced work in physical chemistry (*Fizikokimya alanında ileri seviyede işler yapabileceğimden eminim*)
4 (C3+)					I am sure I can learn physical chemistry (*Kimyaya hâkim olabileceğimden eminim*)
5 (C4+)					I think I could handle more difficult physical chemistry (*Üst seviyedeki fizikokimya problemleriyle başa çıkabileceğimi düşünüyorum*)
6 (C5+)					I can get good grades in physical chemistry (*Fizikokimya bilgisi gerektiren derslerde iyi not alabilirim*)
7 (C6+)					I have a lot of self-confidence when it comes to physical chemistry (*Fizikokimya konusunda kendime çok güveniyorum*)
8 (C7-)					I'm no good at physical chemistry (*Fizikokimya konusunda hiç iyi değilim*)
Factor 2: satisfaction					
14 (S1+)	0.901	8.184	−0.626	−0.414	It would make me happy to be recognized as an excellent student in physical chemistry (*Fizikokimya konusunda mükemmel bir öğrenci olarak bilinmek beni mutlu eder*)
15 (S2+)					I'd be proud of to be the outstanding student in physical chemistry (*Fizikokimya konusunda göze çarpan bir öğrenci olmaktan gurur duyarım*)
16 (S3+)					I'd be happy to get top grades in physical chemistry (*Fizikokimya derslerinde en yüksek notları almak beni mutlu eder*)
17 (S4+)					It would be really great to win a prize in physical chemistry (*Fizikokimya*

(continued)

Table 1 (continued)

Item # (scale)	Cronbach alpha	Std. deviation	Skewness	Kurtosis	Item
					derslerinde ödül almak gerçekten harika olur)
18 (S5+)					Being first in a physical chemistry competition would make me pleased (*Fizikokimya konulu bir yarışmada birinci olmak beni memnun eder*)
19 (S6+)					Being regarded as smart in physical chemistry would be great thing (*Fizikokimya derslerinde zeki olarak sayılmak harika olur*)
Factor 3: relevance					
35 (U2+)	0.884	7.950	−0.048	−1.097	I study physical chemistry because I know how useful it is (*Fizikokimya öğrenmeye çalışıyorum çünkü ne kadar yararlı olduğunu biliyorum*)
36 (U3+)					Knowing physical chemistry effectively will help me earn a living (*Kimyayı etkin bir biçimde kullanabilmek hayatımı kazanmama yardımcı olacak*)
38 (U5+)					I will need a firm mastery using physical chemistry in my future work (*İlerideki işlerim için fizikokimya alanında tam bir usta olmaya ihtiyacım olacak*)
39 (U6+)					I will use physical chemistry in many ways as an adult (*Kimyayı hayatımın her alanında pek çok şekilde kullanabilirim*)
40 (U7-)					Physical chemistry is of no relevance to my life (*Kimyanın benim hayatımda hiçbir etkisi yok*)
41 (U8-)					Physical chemistry will not be important to me in my life's work (*Fizikokimya benim için ileriki hayatımda önemli olmayacak*)
Factor 4: personal ability					
10 (C9-)	0.819	8.052	0.221	−1.122	I am not the type to do well in physical chemistry (*Kimyada iyi birisi değilim*)
11 (C10-)					For some reasons even though I study, physical chemistry seems unusually hard for me (*Ne kadar uğraşsam da fizikokimya bana zor geliyor*)

(continued)

Table 1 (continued)

Item # (scale)	Cronbach alpha	Std. deviation	Skewness	Kurtosis	Item
12 (C11-)					Most subjects I can handle OK, but I have a knack of mucking up physical chemistry (*Pek çok konuyu halledebiliyorum ama fizikokimya konusunda sorun yaşıyorum*)
13 (C12-)					Physical chemistry has been my worst courses (*Fizikokimya ile ilgili dersler her zaman en kötü derslerim olmuştur*)
Factor 5: gender difference					
26 (MD1+)	0.857	8.369	−1.036	0.139	Females are as good as males in physical chemistry (*Kimyada kızlar da erkekler kadar iyidir*)
27 (MD2+)					Studying physical chemistry is just as appropriate for girls as it is for boys (*Fizikokimya ile ilgili bir bölüm okumak erkekler için olduğu kadar kızlar için de uygundur*)
28 (MD3+)					I would trust a woman just as much as I would trust a man to figure out important physical chemistry calculations (*Fizikokimya problemlerini çözmede bir kıza da erkeğe güvendiğim kadar güvenirim*)
29 (MD6+)					Women certainly are logical enough to do well in physical chemistry (*Kızlar kesinlikle fizikokimya konusunda iyi olacak kadar yeterli mantığa sahiptirler*)
Factor 6: interest					
52 (EM7-)	0.781	8.341	−0.770	−0.054	Figuring out physical chemistry problems does not appeal to me (*Kimyada karşılaştığım problemleri çözmek ilgimi çekmiyor*)
53 (EM8-)					The challenge of physical chemistry problems does not appeal to me (*Kimyada karşılaştığım problemlerin zorluğu ilgimi çekmiyor*)
54 (EM9-)					Physical chemistry puzzles are boring (Fizikokimya sıkıcıdır)

(continued)

Table 1 (continued)

Item # (scale)	Cronbach alpha	Std. deviation	Skewness	Kurtosis	Item
Factor 7: social influence					
22 (S9-)					If I had good grades in physical chemistry, I would try to hide it (Fizikokimya derslerinde iyi notlar alırsam bunu saklamaya çalışırım)
23 (S10-)					If I got the highest grade in physical chemistry, I'd prefer no one knew (*Fizikokimya derslerinde en yüksek notu alırsam kimsenin bilmesini istemem*)

Notes
1. FSMAS acronyms: *C* confidence, *S* success, *U* usefulness, *MD* male domain, *EM* affective motivation
2. Negatively worded items—those marked with a minus sign—were inversely weighed
3. Items 22 and 23 had high (>±2.5) skewness and kurtosis values so they were removed from the analysis. This eliminates the factor 7, social influence, from further analysis

is much stable because every variable has the same variability (i.e., the standard deviation is 10).

Cronbach alpha analysis reveals that the mFSMAS used in this study is highly reliable. Alpha values ranged from 0.781 to 0.901.

With respect to the normality condition of the composite *T*-scores in Table 1, skewness and kurtosis values confirm that the distributions are close to a normal curve so the data may be analyzed through parametric analyses such as *t*-test and Pearson correlation. Mean comparisons are performed to investigate if gender-based differences exist.

In the following subheadings are the highest loaded items[2] along with their statistics describing the overall perceptions of the participants on learning PChem II topics. Also, gender-based comparisons for composite *T*-scores are reported for each factor.

4.2.1 Factor 1: Confidence in Learning Physical Chemistry

Item 4, "I am sure I can use physical chemistry" ($M = 2.48$; $SD = 1.35$), represents this factor. The highest value of the Likert scale was 7 (i.e., referring to "Agree"), and so the mean value of this item shows students' confidence in learning and using physical chemistry is lower than average of the scale. Thus, students in general are not confident in learning physical chemistry. [To clarify, item 4 was chosen to represent this category because of its highest factor loading but not because of its

[2] The highest loaded items were determined by the EFA results of an earlier study of mFSMAS by Kahveci (2009).

item-based meaning in words. Our interpretation is based on the factor onto which individual items loaded: confidence in learning physical chemistry.] There was no statistically significant difference in the composite confidence *T*-scores of female ($M = 49.00$; SD = 5.74) and male ($M = 51.64$; SD = 10.44) students; $t\ (27) = -.88$, $p = 0.053 > 0.05$. Although both gender groups are in agreement with respect to their perception of low confidence toward physical chemistry, male students' perceive that they have higher confidence than female students.

4.2.2 Factor 2: Satisfaction

Item 17 is "It would be really great to win a prize in the courses in which we use physical chemistry" ($M = 5.03$; SD = 2.00). Students tended to have highly positive attitudes about their satisfaction in learning physical chemistry. There was no statistically significant difference in the composite satisfaction *T*-scores of female ($M = 51.88$; SD = 8.13) and male ($M = 46.92$; SD = 7.65) students; $t\ (27) = 1.63$, $p = 0.53 > 0.05$. However, female students tend to report more satisfaction toward physical chemistry.

4.2.3 Factor 3: Relevance

Item 36 best represents this category: "Using physical chemistry effectively will help me earn a living" ($M = 4.10$; SD = 1.80). The mean value for this item implies that all of the students regardless of their gender, grade level, and major have neutral attitudes about the relevance of physical chemistry in their life. There was no statistically significant difference in the composite relevance *T*-scores of female ($M = 49.97$; SD = 6.96) and male ($M = 50.05$; SD = 9.73) students; $t\ (27) = -0.03$, $p = 0.08 > 0.05$.

4.2.4 Factor 4: Perceived Personal Ability

Item 12 is "Most subjects I can handle okay, but I have a knack for flubbing up the problems about physical chemistry." This statement refers to a negative attitude in the instrument. When it is reverse coded for the analysis, the item reads: "Most subjects I can handle okay, but I do not have a knack for flubbing up the problems about physical chemistry" ($M = 3.38$; SD = 2.16). In general, students tended to perceive that they were able to learn physical chemistry in a moderate level. There was no statistically significant difference in the composite perceived personal ability *T*-scores of female ($M = 48.72$; SD = 7.42) and male ($M = 52.10$; SD = 8.96) students; $t\ (27) = -1.10$, $p = 0.37 > 0.05$. Male students feel better than female students with respect to perceived personal ability toward physical chemistry.

4.2.5 Factor 5: Gender Difference

Item 27, "Studying in a department related to physical chemistry is just as appropriate for girls as it is for boys" ($M = 5.86$; $SD = 1.79$), best represents gender difference category. High mean value implies that students have positive attitudes toward women in physical chemistry fields. In other words, in general students tend to think that women do have a socially constructed support in their success of learning physical chemistry. There was no statistically significant difference in the composite gender difference T-scores of female ($M = 48.82$; $SD = 9.07$) and male ($M = 50.30$; $SD = 7.49$) students; $t\ (27) = -0.15$, $p = 0.60 > 0.05$. It is worth nothing that the male students scored this attitude higher than their female counterparts.

4.2.6 Factor 6: Interest

Item 53 is "The challenge of physical chemistry related problems does not appeal to me." This statement refers to a negative attitude in the instrument. When it is reverse coded for the analysis, the item reads "The challenge of physical chemistry related problems does appeal to me" ($M = 5.28$; $SD = 1.93$), which best represents the interest category. All of the students agreed that they have close to high level interest in problems related to physical chemistry. There was no statistically significant difference in the composite interest T-scores of female ($M = 50.45$; $SD = 8.96$) and male ($M = 49.26$; $SD = 7.57$) students; $t\ (27) = 0.37$, $p = 0.42 > 0.05$. This result shows that female students have higher interest toward physical chemistry than male students.

4.3 Correlation Analysis Between mFSMAS and RTOP Scales

A detailed analysis of RTOP scales is not meant to be provided here because this study relies on student attitudes toward physical chemistry, which means the mFSMAS scale is in the main focus. However, in order to understand student attitudes better, RTOP survey was administered to students to get a sense of (1) how they perceive the nature of PChem II classes and (2) how their perceptions of the nature of course correlate with their attitudes toward learning in the course.

As a descriptive approach, when Appendix 2 was investigated, it is clear that PChem II courses are far from inquiry-based science-teaching qualities. All items are rated below 3. [Likert scale 5 means agree, and 1 means disagree in this scale. Roughly speaking, items having a mean value close to one refer to less chance to observe inquiry-based science-teaching elements.] Cronbach alpha analysis of RTOP shows that the scale is highly reliable; five subcategories of which ranged from 0.67 to 0.83.

Table 2 Correlations between mFSMAS and RTOP scales

		TSCORE_FENNEMA_MEAN	TSCORE_INQUIRY_MEAN
TSCORE_FENNEMA_MEAN	Pearson correlation	1	0.487[a]
	Sig. (2 tailed)		0.007
	N	29	29
TSCORE_INQUIRY_MEAN	Pearson correlation	0.487[a]	1
	Sig. (2 tailed)	0.007	
	N	29	29

[a]Correlation is significant at the 0.01 level (two tailed)

So the descriptive analysis of RTOP survey suggests that PChem II courses are teacher oriented, with students being in more of a recipient mode.

Table 2 shows the correlations of mFSMAS and RTOP scales. A unique composite T-score was produced for each survey. *T*-scores are preferred because they are standardized. Raw scores would yield messy mean values as each variable has different standard deviations. Any correlations of the new variables would indicate if there is any effect of teaching strategy on students' attitudes toward physical chemistry. In fact, these two variables were strongly correlated, $r(27) = 0.49$, $p < 0.01$.

This finding suggests that reform-based teaching strategies would yield more positive student attitudes toward physical chemistry.

5 Conclusions

The following search keywords were run over Google Scholar to see other studies focusing on students' attitudes toward physical chemistry:

- "Physical chemistry" and "attitudes"
- "Physical chemistry" and "motivation"
- "Physical chemistry" and "Fennema-Sherman"

However, there were no relevant studies which came up on these search topics. Thus, with the best of our knowledge, this study is among the few (if others exist) which attempt to profile majors' attitudes toward physical chemistry.

Findings indicate that, in general, students do not feel confident in learning physical chemistry, do not take physical chemistry as relevant to their lives (imagine that they would be chemist in near future), and feel that they have moderate level ability to learn physical chemistry. These are not desired affective states for competitive young chemists.

However, students have high positive levels of satisfaction toward learning physical chemistry and rate that women in science are no different than men in science, and despite the current teaching practices (i.e., lecture only, teachers' notes are the main reference), they have moderate to high interest in learning physical chemistry.

Although reform-based teaching strategies are not mostly present in the present classes observed, based on the results of the current study if those strategies were implemented, students' affective states toward physical chemistry would be more positive. This finding implies the model fit presented in Fig. 1 as well as the construct validity of mFSMAS.

6 Limitations of the Study

This study is limited in terms of sample size. A larger sample size would lead to more informative statistics such as a full cycle of exploratory factor analysis and ANOVA analysis with advanced post hoc comparisons.

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Appendix 1

mFSMAS data descriptive statistics (non-standardized scores)

	N	Minimum	Maximum	Mean[a]	Std. deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. error	Statistic	Std. error
FENNEMA1	29	1	7	4.24	1.976	−0.062	0.434	−0.943	0.845
FENNEMA2	29	1	5	1.79	1.114	1.438	0.434	1.415	0.845
FENNEMA3	29	1	6	1.90	1.423	1.553	0.434	1.504	0.845
FENNEMA4	29	1	6	2.48	1.353	0.690	0.434	0.070	0.845
FENNEMA5	29	1	4	1.59	0.907	1.576	0.434	1.765	0.845
FENNEMA6	29	1	7	2.97	1.569	0.656	0.434	0.193	0.845
FENNEMA7	29	1	4	1.72	0.922	1.190	0.434	0.682	0.845
FENNEMA8	29	1	7	3.69	2.222	0.149	0.434	−1.509	0.845
FENNEMA9	29	1	7	4.45	2.277	−0.269	0.434	−1.547	0.845
FENNEMA10	29	1	7	3.55	2.261	0.047	0.434	−1.643	0.845
FENNEMA11	29	1	7	3.38	2.194	0.523	0.434	−1.068	0.845
FENNEMA12	29	1	7	3.38	2.162	0.678	0.434	−0.961	0.845
FENNEMA13	29	1	7	4.03	2.398	−0.027	0.434	−1.672	0.845
FENNEMA14	29	1	7	5.38	1.781	−0.989	0.434	0.488	0.845
FENNEMA15	29	1	7	5.00	2.121	−0.675	0.434	−0.924	0.845
FENNEMA16	29	1	7	5.86	1.620	−1.332	0.434	1.257	0.845
FENNEMA17	29	1	7	5.03	2.009	−0.533	0.434	−0.947	0.845
FENNEMA18	29	1	7	5.17	1.947	−0.541	0.434	−1.047	0.845
FENNEMA19	29	1	7	5.31	1.966	−0.801	0.434	−0.526	0.845
FENNEMA20	29	1	7	1.59	1.500	2.888	0.434	7.787	0.845
FENNEMA21	29	1	7	3.31	2.792	0.471	0.434	−1.783	0.845
FENNEMA22[b]	29	1	7	6.66	1.173	−4.391	0.434	20.722	0.845

(continued)

mFSMAS data descriptive statistics (non-standardized scores)									
	N	Minimum	Maximum	Mean[a]	Std. deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. error	Statistic	Std. error
FENNEMA23[c]	29	1	7	6.59	1.211	−3.914	0.434	16.998	0.845
FENNEMA24[d]	29	1	7	1.38	1.178	4.257	0.434	19.803	0.845
FENNEMA25	29	1	7	1.97	2.079	2.100	0.434	2.787	0.845
FENNEMA26	29	1	7	5.17	2.189	−0.763	0.434	−0.822	0.845
FENNEMA27	29	1	7	5.86	1.787	−1.350	0.434	0.730	0.845
FENNEMA28	29	1	7	5.90	1.819	−1.632	0.434	1.856	0.845
FENNEMA29	29	1	7	5.59	1.955	−1.094	0.434	0.019	0.845
FENNEMA30	29	1	7	1.69	1.538	2.337	0.434	4.958	0.845
FENNEMA31	29	1	7	2.52	2.098	1.170	0.434	0.068	0.845
FENNEMA32	29	1	7	1.93	1.907	1.930	0.434	2.400	0.845
FENNEMA33	29	1	7	1.76	1.902	2.412	0.434	4.417	0.845
FENNEMA34	29	1	7	3.93	2.170	0.095	0.434	−1.260	0.845
FENNEMA35	29	1	7	4.21	1.840	−0.031	0.434	−1.017	0.845
FENNEMA36	29	1	7	4.10	1.800	0.269	0.434	−0.885	0.845
FENNEMA37	29	1	7	4.24	1.883	0.142	0.434	−0.964	0.845
FENNEMA38	29	1	7	3.17	1.983	0.452	0.434	−1.005	0.845
FENNEMA39	29	1	7	3.28	1.944	0.459	0.434	−0.936	0.845
FENNEMA40	29	1	7	5.07	2.137	−0.804	0.434	−0.776	0.845
FENNEMA41	29	1	7	5.31	1.948	−0.752	0.434	−0.843	0.845
FENNEMA42	29	1	7	3.41	1.937	0.346	0.434	−1.083	0.845
FENNEMA43	29	1	7	2.28	1.771	1.249	0.434	0.568	0.845
FENNEMA44	29	1	7	2.48	2.029	1.185	0.434	0.040	0.845
FENNEMA45	29	1	7	3.97	2.195	−0.149	0.434	−1.437	0.845
FENNEMA46	29	1	7	3.24	2.198	0.645	0.434	−0.892	0.845
FENNEMA47	29	1	7	2.86	1.866	0.853	0.434	−0.199	0.845
FENNEMA48	29	1	7	3.10	1.780	0.649	0.434	−0.193	0.845
FENNEMA49	29	1	7	2.86	1.747	1.306	0.434	1.309	0.845
FENNEMA50	29	1	7	3.24	2.149	0.777	0.434	−0.736	0.845
FENNEMA51	29	1	7	4.17	2.361	−0.046	0.434	−1.545	0.845
FENNEMA52	29	1	7	4.90	2.076	−0.624	0.434	−0.937	0.845
FENNEMA53	29	1	7	5.28	1.925	−1.035	0.434	−0.043	0.845
FENNEMA54	29	1	7	4.14	2.310	−0.162	0.434	−1.440	0.845
FENNEMA55	29	1	7	2.69	1.966	1.164	0.434	0.379	0.845
FENNEMA56	29	1	7	3.07	2.137	0.871	0.434	−0.644	0.845
FENNEMA57	29	1	7	2.90	1.718	0.625	0.434	−0.225	0.845
Valid *N* (list wise)	29								

[a]Mean values are based on the Likert scale, which ranged from disagree (1) to agree (7). The items having negative meaning are reversed to match the positive items
[b]Omitted from further analysis due to higher than ±2.5 skewness and kurtosis values
[c]Omitted
[d]Omitted

Appendix 2

RTOP data descriptive statistics (non-standardized scores)

	N	Minimum	Maximum	Mean	Std. deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. error	Statistic	Std. error
INQUIRY1	29	1	5	2.62	1.015	0.198	0.434	0.190	0.845
INQUIRY2	29	1	5	2.03	1.149	0.839	0.434	−0.096	0.845
INQUIRY3	29	1	5	1.93	1.163	1.021	0.434	0.146	0.845
INQUIRY4	29	1	5	2.21	1.114	0.726	0.434	−0.094	0.845
INQUIRY5	29	1	3	1.86	0.789	0.257	0.434	−1.320	0.845
INQUIRY6	29	1	5	3.90	1.145	−0.705	0.434	−0.277	0.845
INQUIRY7	29	1	5	3.14	1.217	0.102	0.434	−0.954	0.845
INQUIRY8[a]	29	1	5	4.55	1.021	−2.422	0.434	5.385	0.845
INQUIRY9	29	1	5	3.24	1.327	−0.084	0.434	−1.087	0.845
INQUIRY10	29	1	5	3.17	1.365	−0.334	0.434	−1.066	0.845
INQUIRY11	29	1	5	2.24	1.272	0.741	0.434	−0.432	0.845
INQUIRY12	29	1	5	2.03	1.085	1.009	0.434	0.613	0.845
INQUIRY13	29	1	4	2.03	1.210	0.710	0.434	−1.113	0.845
INQUIRY14	29	1	4	2.00	1.035	0.623	0.434	−0.806	0.845
INQUIRY15	29	1	5	2.55	1.152	0.391	0.434	−0.312	0.845
INQUIRY16	29	1	5	2.03	1.149	1.294	0.434	1.365	0.845
INQUIRY17	29	1	5	3.07	1.223	−0.014	0.434	−0.875	0.845
INQUIRY18	29	1	5	2.07	1.223	1.119	0.434	0.493	0.845
INQUIRY19	29	1	4	2.00	0.886	0.661	0.434	−0.052	0.845
INQUIRY20	29	2	5	3.83	1.071	−0.194	0.434	−1.370	0.845
INQUIRY21	29	1	5	2.55	1.183	0.563	0.434	−0.543	0.845
INQUIRY22	29	1	5	2.38	1.015	0.683	0.434	0.294	0.845
INQUIRY23	29	2	5	4.41	0.867	−1.306	0.434	0.746	0.845
INQUIRY24	29	1	5	3.41	1.240	−0.271	0.434	−0.854	0.845
INQUIRY25	29	1	5	2.83	1.256	0.000	0.434	−0.766	0.845
Valid *N* (list wise)	29								

[a]Omitted from further analysis due to higher than ±2.5 kurtosis value

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