The versions of record is:

Taber, K. S. (2015). Meeting Educational Objectives in the Affective and Cognitive Domains: Personal and Social Constructivist Perspectives on Enjoyment, Motivation and Learning Chemistry. In M. Kahveci & M. Orgill (Eds.), *Affective Dimensions in Chemistry Education* (pp. 3-27): Springer Berlin Heidelberg.

Meeting educational objectives in the affective and cognitive domains: Personal and social constructivist perspectives on enjoyment, motivation and learning chemistry

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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. The present 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 make 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.

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 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 and 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 (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.

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 and Easley 1978; Driver and Erickson 1983; Gilbert and Watts 1983; Glasersfeld 1989) who have drawn upon key constructivist thinkers (Piaget 1929/1973; Kelly 1963; Ausubel 1968; Vygotsky 1934/1986). There are still many 'flavours' to constructivist thinking reflected in science education (Bickhard 1998; Grandy 1998; Bodner et al. 2001), but there is sufficient consensus on the core ideas for constructivism to have become very widely accepted as a basis for teaching (Driver et al. 1994; Matthews 1998; Tobin 1993; Yager 1995; Fensham 2004), and also as the starting point for a major research programme (Taber 2009, 2006).

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 and Taylor 2001; Taber 2010b, 2001, 2000). 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 and 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.

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 et al. 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 (i) that at the lowest levels of the taxonomy it is difficult to distinguish affective from cognitive factors; and (ii) 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 et al. 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 and 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 (Maslow 1970; Koltko-Rivera 2006) beyond the need for self-actualization - 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.

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 Figure 1). Conversely, if students with high skills 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, 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.

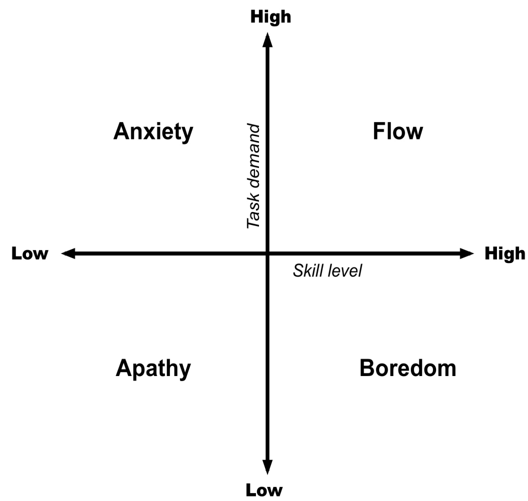

Figure 1: Learners are said to be able to experience 'flow' when they are set demanding learning activities and have sufficient skills to be successful in meeting the demands

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 et al. 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 and 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 Figure 2).

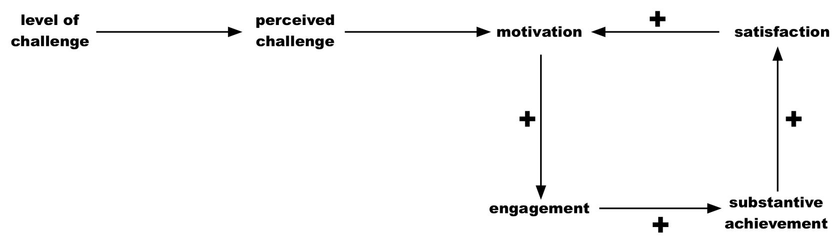

Figure 2: Success in meeting challenges can motivate further engagement in learning. The '+' signs indicate the potential for feedback effects, as a change (increase or decrease) in one factor is likely to lead to the same direction of change in the next

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 de-motivated. That matches the set of conditions in which flow is said to be possible. In the remainder 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.

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 (Gilbert and Watts 1983; Driver and Erickson 1983; Driver and Easley 1978; Gilbert et al. 1982; Osborne and 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 and 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 and 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 and 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 et al. 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).

Applying principles from constructivism with due concern for the affective domain

The argument made in this chapter is that although (i) 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 (that is, the focus is often on how constructivist ideas inform teaching by paying attention to *the cognitive* processes involved in learning); (ii) 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 et al. 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 and 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.

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 and Bretz 2012).

Generally, then, this means that the constructivist teacher should only look to move on after presenting an idea if *both* (i) students' comments, spontaneous questions and responses to teacher questions suggest they have understood the idea, and (ii) 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 judgment 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 and 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 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).

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 (e.g., 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 and 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 pre-requisite knowledge for others, and so to offer a logical teaching (and so learning) order (Herron et al. 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 and Pino-Pasternak 2010) that allows us to understand the actions of other people in terms of their desires, intentions, feelings etc. Young children commonly over-generalise 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 and 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.

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 de-motivating, 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 and 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 and 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.

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 concepts 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 time-scales in relation to particular learning, and potential conditions that might accelerate consolidation. Again then, the constructivist teacher needs to not only 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.

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 (1934/1986) 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 pre-requisite 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 Figure 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 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.

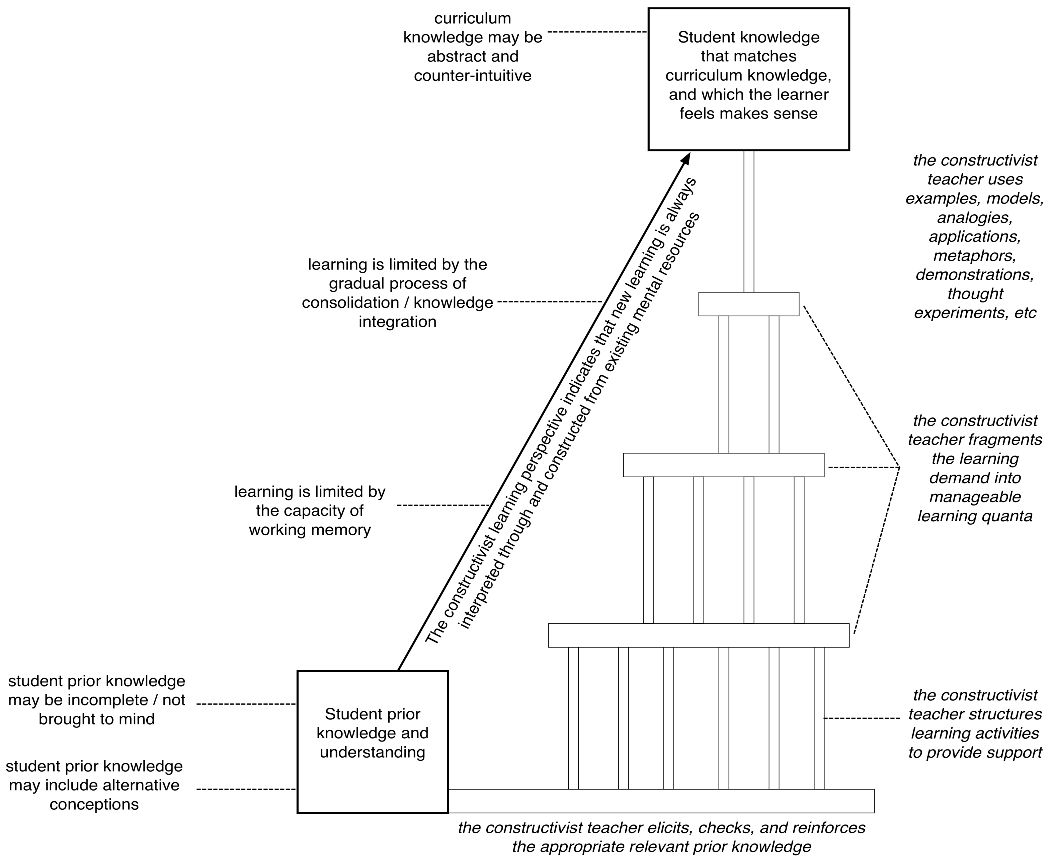

Figure 3: Constructivist teaching involves scaffolding learning

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 Figure 1). Insufficient support (or scaffolding faded before students have made enough progress), however, may lead to failure and frustration (and so anxiety, cf. Figure 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 Figure 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 Figure 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.

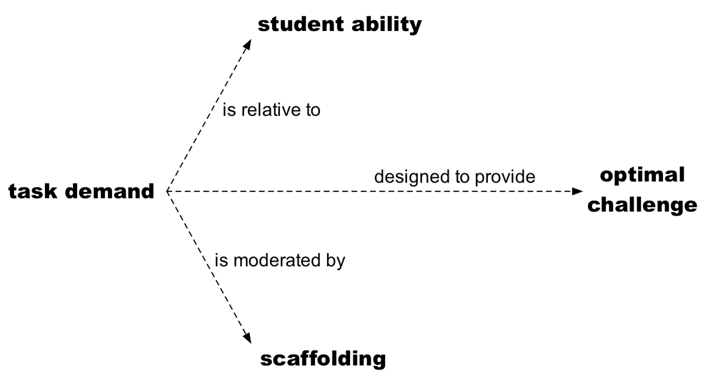

Figure 4: The teacher seeks to offer optimal demand by matching the learning activity and support provided to the ability of the learner

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 and 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 et al. 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' judgments 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 is 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 life-world attitude (Schutz and 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.

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.

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 et al. 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; 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 Chapter 6). 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. None-the-less, 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.

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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