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RESEARCH REPORT

A Motivational View of Constructivist-informed Teaching

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Constructivist and conceptual change perspectives on learning have given rise to a number of models of constructivist classroom teaching. Motivation has been recognized as an important factor in the construction of knowledge and the process of conceptual change, so one could expect that motivation strategies would be integral components of constructivist-informed teaching. The purpose of this paper was to examine, by literature review, the extent to which motivation strategies have been included in extant models of constructivist-informed teaching. The study involved the development of a list of motivation strategies, based on current motivation constructs. Several constructivist-informed teaching models were then analysed. It was found that these models were rather limited in the extent to which they had explicitly integrated motivation. It was also found that some aspects of the models were not entirely in accord with current views of motivation. Finally, a motivational model of constructivist-informed teaching was developed and its three components were described.

Introduction

Classroom teaching practice is likely to be more effective when it is informed by an understanding of how students learn. It is therefore important that the major implications of learning theory should be reflected in classroom practice. Constructivism is the dominant paradigm of learning in science, and a huge amount of science education research has been carried out from a constructivist perspective. However, the question of how to implement classroom teaching that is consistent with a constructivist view of learning is still an issue of concern. Over the past two decades, a number of models of constructivist-informed teaching have been proposed, but at this stage none of them has gained wide acceptance.

The main purpose of this paper is not to analyse constructivist theory, but rather to focus on the classroom teaching models that have developed from it, and to high-

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light the role of motivation. Ritchie (1998) has emphasized the importance of using constructivism as a referent for classroom practice, and in the present paper the term "constructivist-informed teaching" will be used to refer to teaching that is informed and guided by a constructivist view of learning.

The first part of the paper will briefly describe the constructivist view of learning, in order to demonstrate that motivation is recognized as a crucial factor in the construction of knowledge. The second section will summarize a range of motivation constructs and their implications for classroom practice. The purpose of this will be to create a list of motivation strategies that could be used in classrooms. The third section will examine some models of constructivist-informed teaching, in order to determine the extent to which motivation strategies have been included in them. Finally, as there were some concerns about the extant models, a motivational model of constructivist-informed teaching will be proposed.

Constructivism and Conceptual Change

Recent research in science education has been dominated by a constructivist view of learning. According to this view, students do not passively absorb information but, rather, meaningful learning involves the active creation and modification of knowledge structures (Carey, 1985). When students are learning about science they use their existing knowledge, beliefs, interests, and goals to interpret any new information, and this may result in their ideas becoming modified or revised. In this way, learning proceeds as each individual's conceptual schemes are progressively "reconstructed" as he or she becomes exposed to new experiences and ideas (Driver, 1989).

Although the constructivist perspective is pre-eminent in science, there is a range of opinion as to the manner in which the process of knowledge construction occurs. Phillips (1995) has analysed the features of many of the varieties of constructivism that have been proposed, including the views of authors such as von Glasersfeld, Kant, Kuhn, Piaget, and Dewey. Phillips found that the variants differed according to the extent to which they focused on knowledge construction within individuals rather than knowledge construction within disciplines, and they also varied in the extent to which they proposed that knowledge is either made or discovered. However, with respect to individuals' learning in schools, the two quintessential forms of constructivism were those proposed by Piaget and Vygotsky, so they will be briefly described.

The "cognitive constructivist" viewpoint developed from the ideas of Jean Piaget, and emphasizes the importance of the cognitive processes that occur within individuals (Osborne & Wittrock, 1983; Piaget, 1978). Proponents of this view argue that individuals strive to make sense of the world (von Glasersfeld, 1987), and the metaphor of the "child as scientist" is often used to describe how children investigate the world around them (Driver & Erikson, 1983). This type of learning can be triggered by experiences that can be physical, mental, or social: physical experiences include physical interaction with objects in the environment; mental experiences involve thinking about things they have observed; and social experiences include interactions with adults and peers. Individuals interpret these experiences in order to make meaning and develop their own personal understandings. Cognitive constructivism therefore emphasizes the personal construction of knowledge. According to this view, teachers have the relatively peripheral role of providing suitable experiences that will facilitate learning.

On the other hand, "social constructivism" developed from the ideas of Lev Vygotsky, and emphasizes the importance of society, culture, and language (Lemke, 2001; Vygotsky, 1978). According to this perspective, knowledge is socially constructed and learning takes place in particular social and cultural contexts. Social interaction provides children with ways of interpreting the physical and social world, and students thus become enculturated into ways of thinking that are common practice in that specific community. Much learning occurs when children interact with more competent individuals such as adults and teachers. Through a process of scaffolding, a teacher can gradually guide students to develop their knowledge and skills while making connections with students' existing schemes. Through language, students are able to share ideas and seek clarification until they understand. The emphasis is on a communication-rich environment in which students are given opportunities to interact with adults and peers in order to negotiate meaning. According to this view, teachers have a central role in providing guidance and support to learners.

The cognitive constructivist and social constructivist perspectives emphasize different paths towards knowledge construction, but there are important commonalities. Marín, Bennaroch, and Jiménez Gómez (2000) compared the two perspectives and found that one source of common ground was the characteristics of students' conceptions, or ways of perceiving reality. In addition, there is one other important area of similarity—according to both views, learning is seen as an active rather than a passive process, as ultimately each individual reconstructs his/her own understandings in response to environmental stimuli. Regardless of whether the environmental stimulus is teacher scaffolding or direct experience with everyday life phenomena, the student is still required to access their pre-existing knowledge and beliefs, link these to what is currently being experienced, and modify them if necessary (Driver & Oldham, 1986; Phillips, 1995; Roth, 1994; von Glasersfeld, 1987). Thus, according to both views, the reconstruction of meaning requires effort on the part of the learner.

If effort is required for learning then it follows that motivation is also required, because students will not make that effort unless they are motivated to do so. Motivation would therefore be required to initially arouse students to want to participate in learning, and it would also be needed throughout the whole process until knowledge construction has been completed. Constructivist theory thus implicates motivation as a necessary prerequisite and co-requisite for learning.

However, most of the research on constructivism and science learning has not focused on motivation. Instead, a huge number of studies in science education have been devoted to the description and analysis of students' conceptions (see Pfundt & Duit, 1991). This research has been informative in increasing our understanding of students' starting points for learning. In many instances students' views have been shown to be scientifically inaccurate, in which case they have been referred to as “misconceptions” or “alternative conceptions”. It is generally agreed that misconceptions occur in all branches of science, they are widespread among students, they can be resistant to conventional teaching, and they can interfere with future learning (Hewson et al., 1999; Wandersee, Mintzes, & Novak, 1994).

In recognition of the challenge posed by misconceptions, learning science is often viewed as a process of “conceptual change”. Probably the most widely-accepted model of conceptual change is that proposed by Posner, Strike, Hewson, and Gertzog (1982). They argued that conceptual change could take two forms: “assimilation” occurs when individuals add information to existing knowledge structures, but “accommodation” is a more radical change that occurs when a central concept is replaced or reorganized. The advantage of this model was that it provided an explanation of the conditions necessary for conceptual change. Accommodation will begin when there is dissatisfaction with an existing conception, then it will proceed as the student considers a new conception to be more intelligible (able to be understood), plausible (makes sense), and fruitful (having the potential to explain more situations). The “status” of a conception would be marked by the extent to which it is intelligible, plausible and fruitful (Hewson & Thorley, 1989). However, the disadvantage of this model was that it did not contain a component for the motivational forces that would be necessary to drive the conceptual change process. Instead, the authors acknowledged their focus to be on the rational component of learning:

> Our central commitment in this study is that learning is a rational activity … It does not, of course, follow that motivational or affective variables are unimportant to the learning process. The claim that learning is a rational activity is meant to focus attention on what learning is, not what learning depends on. (Posner et al., 1982, p. 212)

More recent studies have identified several factors that may influence conceptual change. Hewson et al. (1999) argued that a student’s “conceptual ecology” can moderate learning:

> The conceptual ecology consists of many different kinds of knowledge, the most important of which may be epistemological commitments (e.g. to consistency or generalisability), metaphysical beliefs about the world (e.g. the nature of time), and analogies and metaphors that might serve to structure new information. (p. 251)

Encouraging students to engage in metacognition (i.e., the conscious awareness and management of cognition and learning) has also been shown to facilitate the process (Beeth & Hewson, 1999; White & Gunstone, 1989).

In addition, motivation is recognized as a factor affecting conceptual change. Pintrich, Marx, and Boyle (1993) highlighted “the theoretical difficulties of a cold, or overly rational, model of conceptual change that focuses only on student cognition without considering the ways in which students’ motivational beliefs … can facilitate or hinder conceptual change” (p. 167). They argued that conceptual change would largely be influenced by three factors—the choice to engage in the task, the level of engagement in the task, and the willingness to persist at the task—all of which are behavioural indicators of motivation. Tyson, Venville, Harrison, and Treagust (1997) supported this view. They proposed a multidimensional framework in which conceptual change is influenced by social/affective conditions such as motivation, as well as ontology (beliefs about the fundamental nature of the thing being studied) and epistemology (beliefs about the nature of knowledge). More recently, Sinatra and Pintrich (2003) emphasized the "metacognitive, motivational and affective processes that can be brought under the learner's conscious control and may determine the likelihood of change" (p. 2). They argued that motivation is an important controlling factor in the conceptual change process, and introduced the idea of "intentional conceptual change" to describe situations in which the construction of knowledge is goal-directed and under the learner's control.

These cited studies have provided evidence that motivation is an integral factor in the construction of knowledge. Consequently, one would expect motivation strategies to be an integral component of constructivist classroom teaching. However, it is first necessary to identify what these motivational strategies might be. The following section will summarize current motivation constructs and their implications for classroom practice.

Motivation Constructs

Motivation has been defined as an "internal state that activates, guides, and maintains behaviour" (Green, 2002, p. 989). From an educational point of view, the term "motivation" can therefore apply to any process that activates and maintains learning behaviour. Much of the research in this area has been carried out from either a behaviourist perspective or a social cognitive perspective. The former emphasizes the influence of environmental factors such as rewards, whereas the latter emphasizes the importance of students' beliefs about themselves and their learning environment. Most of the recent research has adopted the social cognitive view. In contrast to older models in which motivation was assumed to be a relatively stable personality trait, the social cognitive view is that motivational beliefs can be significantly influenced by aspects of the classroom context (Pintrich & Schunk, 1996). This is a particularly important point because it indicates that classroom strategies can be used to optimize student motivation. A variety of constructs have been proposed that have the potential to inform motivation in school settings, and these are outlined in the following.

Firstly, motivation has been described as either "extrinsic" or "intrinsic". Ryan and Deci (2000) defined these in the following way: "Intrinsic motivation … refers to doing something because it is inherently interesting or enjoyable, and extrinsic motivation … refers to doing something because it has a separable outcome" (p. 55). Extrinsic motivation therefore focuses on factors external to the individual and the task, such as rewards, praise, privileges, or attention. For example, a teacher might give students a sticker for work completed. This type of motivation is often used in classrooms, but its effectiveness has been questioned—a meta-analysis by Deci, Koestner, and Ryan (2001) showed that expected, tangible rewards (as distinct from unexpected rewards or verbal praise) had a strong negative influence on other types of motivation. On the other hand, intrinsic motivation is directly related to the task being performed. According to intrinsic motivation theory (White, 1959), a person feels instinctive pleasure when he/she learns something new or succeeds in a challenging task. This creates feelings of confidence and mastery that are self-reinforcing, so the student will be more inclined to engage in future learning activities, simply for the enjoyment of succeeding. Intrinsic motivation is generally considered to be more effective in promoting learning and achievement (Deci et al., 2001).

Lepper and Hodell (1989) proposed that intrinsic motivation could be enhanced in the classroom by providing challenge, curiosity, fantasy, and control. *Challenge* refers to a moderate level of difficulty that will allow students to experience a sense of mastery and competence when they succeed. The level of challenge presented by a task will vary from student to student according to their capabilities, but Stipek (2002) argued that these differences can be compensated for by allowing students to work at their own pace some of the time, or setting extension work for early finishers. *Curiosity* is evoked by novel, discrepant, or unusual experiences—when students have their curiosity aroused they are interested in resolving the inconsistencies they have observed. For example, discrepant events demonstrations, which have a surprising or unexpected result, have often been used in science classrooms to capture the attention of students (Banet & Núñez, 1997; Nussbaum & Novick, 1982). Intrinsic motivation can also be enhanced when activities draw upon students' imaginations and *fantasies*, as these allow students to step out of real life and to make comparisons with real life. The idea of *control* refers to students' feelings of self-determination and autonomy—students are more likely to be motivated when they perceive themselves to be in control of their behaviour. For example, Black and Deci (2000) found that students' perceptions of self-determination in a college chemistry course influenced their performance in that course. Self-determination may be enhanced, for example, by allowing students to choose work partners or the timing of work to be done, or by allowing choice in assignment tasks. However, Ryan and Deci (2000) reviewed a number of studies and found that self-determination and autonomy are diminished by external rewards, competition, and deadlines.

Much of the recent work on student motivation has been informed by "achievement goal theory" (Ames, 1992; Kaplan & Maehr, 1999; Pintrich, 2000; Urdan & Maehr, 1995). Students may have a range of personal goals, including social goals (e.g., gaining the approval of teachers or peers), mastery goals (learning or mastering the work), and performance goals (demonstrating their ability to others by getting a good grade or getting a higher grade than their peers). Of these, mastery goals have consistently been shown to be the most beneficial, being related to use of deep learning strategies and enhanced performance (Anderman & Maehr, 1994; Pintrich, 2000). Interestingly, two types of performance goals have been distinguished (Harackiewicz, Barron, Tauer, & Elliot, 2002): "performance-approach" goals are indicated when students try to demonstrate positive ability in comparison with others, but "performance-avoidance" goals focus on putting in a minimum amount of effort in order to avoid looking incompetent to others. Both types of performance goals imply negative effects on motivation because part of the student's focus is on other students rather than the content. It follows that, in the classroom, activities involving competition and comparison should generally be avoided. However, some recent studies have indicated that students may have multiple goals, and this may modify the effect of classroom activities. For example, some students appear to have mastery goals as well as performance-approach goals (i.e., they want to understand the work and do well in comparison with others), and, for these students, competitive activities will not necessarily be detrimental (Pintrich, 2000). However, it is still generally agreed that mastery goals are the more preferable (Xiang, McBride, & Solmon, 2003).

A number of classroom techniques have been proposed to encourage the development of mastery goals. Ames (1992) recommended that classroom tasks should be meaningful and relevant to the students' lives, so there is a perceived benefit in understanding the content. She argued that students should have some autonomy in classroom life, being allowed to participate in shared decision-making, and to make choices about the structure of classroom activities and the types of products they create. It has also been suggested that a variety of different types of activities is desirable, so as to provide relevance to the full range of students in a class (Deemer, 2004; Kaplan & Maehr, 1999). In general, competition should be avoided, as it tends to promote performance goals—Kaplan and Maehr suggested that collaboration in groups should therefore be available, but not used exclusively: "As many tasks as possible should facilitate the creation of diverse participation structures such as working individually or collaboratively, involve active movement and production of artefacts, and allow social interaction among students, whether they work collaboratively or not" (1999, p. 30). Finally, students should be given regular feedback on assessment tasks, and praise should be given for improvement in mastering new work rather than simply for high performance (Xiang et al., 2003). Social comparison of results and feedback should also be avoided, and, instead, students should receive private recognition for their efforts (Deemer, 2004).

A number of studies have also linked motivation to the construct of "interest". Interest is considered a psychological state "characterised by focussed attention, increased cognitive and affective functioning, and persistent effort" (Ainley, Hidi, & Berndorff, 2002, p. 545). Hidi (1990) identified two types of interest: "personal interest" is a long-term preference for a particular topic or domain (a student might have a personal interest in biology, for example), whereas "situational interest" is short-term interest that is aroused by aspects of a specific situation (a spectacular chemistry demonstration could arouse transient interest even in students who are not particularly interested in chemistry). Personal interest is a relatively enduring phenomenon, but the disadvantage is that it is very difficult for teachers to take all students' personal interests into consideration when planning lessons (Chen, Darst, & Pangrazi, 2001). Some research attention has therefore focused on situational interest because it concentrates on classroom events and their immediate impact on students. For example, Flowerday, Schraw, and Stevens (2004) found that situational interest increased students' engagement and use of deep learning strategies, and could actually override the effects of personal interest.

Several sources of situational interest have been identified. Firstly, it can be aroused by discrepant or novel stimuli (Chen et al., 2001; Hidi & Harackiewicz, 2000). Anderman, Noar, Zimmermann, and Donohew (2004) argued that novelty is particularly important in gaining students' initial attention for a task. Mitchell (1997) proposed that "meaningfulness" and "involvement" are additional sources of situational interest in mathematics classes—meaningfulness refers to the personal relevance of the content, whereas involvement refers to the extent to which students are active participants in the lesson. These arguments were supported by Palmer (2004), who found that novelty, meaningfulness, and involvement were important sources of situational interest in science classes for primary teacher education students: novelty was created by the use of discrepant events activities and "strange but true" facts, meaningfulness was created by making activities relevant to primary school classrooms, and involvement occurred when students were active participants in hands-on activities.

The construct of "expectancy-value" concerns students' judgements about their expectations of success and the potential usefulness of the content (Wigfield & Eccles, 1994, 2000). Expectancy beliefs are students' beliefs about their ability and chances of success in performing a particular task, whereas task value refers to the perceived value of the material to be learnt. Three types of values have been identified. "Attainment value" is the extent to which the task relates to the student's self-image. For example, students who consider themselves good at science would want to confirm it by learning science well. "Utility value" concerns the usefulness of the task. For example, learning science might help a student to enter a university medical program. "Intrinsic value" refers to the inherent enjoyment in a task, and is very closely related to the constructs of intrinsic motivation and interest. Research into these constructs has indicated that expectancy beliefs are related to task values and are predictive of students' participation, effort and achievement in learning (VanZile-Tamsen, 2001; Xiang, McBride, & Guan, 2004; Xiang, McBride, Guan, & Solmon, 2004b). Values appear to be closely associated with students' enrolment choices, whereas expectancies have been linked to performance (Greene, DeBacker, Ravindran, & Krows, 1999). It has also been found that gender differences have a strong influence on student values, with mathematics and science having low value for female students who regard them as masculine domains (Stipek & Gralinski, 1991).

A number of classroom factors have been identified that may positively influence students' expectancy-value beliefs. Children's value beliefs about particular subjects are positively correlated with the amount of previous success they have experienced in those subjects (Green, 2002), so ensuring that students experience success is important. Zusho, Pintrich, and Coppola (2003) argued that, in chemistry courses, task value could be enhanced by emphasizing the relationship of the content to everyday life. Green has suggested that task value will be promoted whenever a teacher provides a reason for the task, emphasizes the usefulness and importance of the task, emphasizes the enjoyment that can be gained from the task, offers choice within the task, and models enthusiasm for the task. She also suggested that student expectancies of success can be promoted when teachers use the following types of verbal statements: those that convey confidence in students' abilities to do the task (e.g., "I'm sure you can do this if you try"), those that challenge the students to work at a higher level (e.g., "This is a bit harder than the last thing we did"), and those that confirm that students have succeeded in achieving expectations (e.g., "Everybody did well in that task").

Bandura (1981, 1982) proposed the construct of "self-efficacy" as a belief in one's ability to perform effectively. Self-efficacy is concerned with a person's beliefs that he/she can "organise and execute courses of action required to deal with prospective situations that contain many ambiguous, unpredictable and often stressful, elements" (Bandura, 1981, pp. 200–201). There are two dimensions of self-efficacy: "efficacy expectation" is the belief that one can successfully perform the action, whereas "response-outcome expectancy" is the belief that the action will be effective in achieving the desired outcome. Self-efficacy is situation specific, so an individual may have a high self-efficacy for one task but a low self-efficacy for another. Research has shown that self-efficacy is positively correlated with effort and performance—people with high self-efficacy for a task will persist in their efforts until the task is completed successfully, whereas those with low self-efficacy will tend to give up easily or even avoid the activity. For example, Zusho et al. (2003) found that self-efficacy and task value beliefs were better than SAT mathematics scores for predicting achievement in college chemistry.

Bandura (1997) described four factors that can improve self-efficacy: mastery experiences, vicarious experiences, verbal persuasion, and the physiological/affective state. The most powerful of these are *mastery experiences*, which are authentic previous successes in dealing with a particular challenge. In the classroom, teachers should keep learning tasks at a challenging but achievable level of difficulty so students experience successes in learning. The more often students experience success, the more powerful their self-efficacy will become—so it is generally agreed that students should be presented with frequent, short-term, proximal goals (Pajares, 2002). Palmer (2001) found that providing students with a clear goal or purpose for each science lesson enabled them to set proximal subgoals, and student success in understanding science was facilitated by clear teacher explanations, giving students the opportunity to ask questions to clarify their understandings, and use of hands-on activities that demonstrated each concept. *Vicarious experiences* are those in which a person sees a behaviour modelled by another person, so they feel they could do it too. Pajares argued that teachers provide more effective models when they freely admit when they have made a mistake, as this allows students to see that errors are inevitable and that they can be overcome. Similarly, Zimmerman and Kitsantas (2002) found that a "coping model", of a person who gradually improved his or her technique, was more effective in raising self-efficacy among observers than a "mastery model", of a person who performed that technique flawlessly. McCabe (2003) argued that students should also have the opportunity to work with peers on challenging tasks, so they can provide models for each other. The third source of self-efficacy is *verbal persuasion*, which occurs when a student receives feedback that they have been successful. It is important that students receive praise for effort rather than just achievement, and it has been suggested that teachers could use charts and graphs to highlight positive trends in each student's progress (McCabe). Finally, *physiological/affective states* refers to students' responses to their own bodily stress levels. People who regard their own fear and anxiety as indicators of inability may allow these negative attitudes to reinforce until they become debilitating. However, higher self-efficacy is achieved when people treat anxiety and fear as normal responses that even highly competent individuals may experience in certain situations. Anxiety levels appears to be a particularly important consideration for science students, many of whom have been found to be acutely affected by anxiety, particularly in physical science courses (Udo, Ramsey, Reynolds-Alpert, & Mallow, 2001). To reduce this problem, teachers should create supportive and pleasant classroom atmospheres, for example by "smiling, empathetic listening, voice moderation, frequent use of student's name, appropriate and reassuring facial gestures, affirmative head nodding, and general attentiveness" (McCabe, 2003, p. 18).

"Attribution theory" (Weiner, 1986) concerns students' beliefs about the factors that have caused their past successes or failures, as this could impact on their approaches to future tasks. This construct has three dimensions: locus, stability, and control. Students may have an *internal locus* of causality, in which they perceive that the causes of their success or failures are mainly due to their own ability or effort, whereas an *external locus* of causality refers to factors, such as task difficulty and luck, that are external to the individual. Causes may also be attributed as *stable* over time (students usually regard their ability levels to be stable), whereas *unstable* causes are those that are short-term in duration (effort or luck are usually regarded by students as short-term causes). The idea of *control* refers to how much control students have over the cause—individuals can control the amount of effort they exert, but not the difficulty of the task. As a result of these factors, students may display positive or negative attributions about the causes of their achievement outcomes. For example, Rennie and Dunne (1994) investigated Fijian students' attributions for their performances in science tests, and found that the largest proportion of students attributed their success to effort (a positive attribution). On the other hand, "learned helplessness" is a negative example, which occurs when students who have a history of failure attribute their failure to lack of ability—they believe that ability is not able to be controlled so they have no control over their performance in a task. They consequently exert little effort on the task and are more likely to fail as a result (Firmin, Hwang, Copella, & Clark, 2004). Attributions can therefore substantially affect performance—for example, Yates (2002) found that students' attributional explanations were significantly correlated with their achievement in mathematics.

Several classroom factors may affect students' attributions, and some authors have found that high-quality teaching can override the negative effects of the less desirable attributions (Perry & Magnusson, 1989). Kamins and Dweck (1999) proposed that different forms of teacher feedback can influence young children's performance. They found that process praise or process criticism (i.e., comments that focused on effort and persistence) were more effective in promoting task persistence than were person praise or person criticism (i.e., comments that focused on the person or their ability). In addition, Sutherland and Singh (2004) suggested that behaviours such as learned helplessness would be minimized when teachers use the following techniques: give students more opportunities to respond to questions, as this will allow students more opportunities to be correct; provide praise for correct responses, especially process praise; and model how to deal with difficult tasks (e.g., by thinking aloud).

A Summary of Classroom Motivation Strategies

If motivation is a prerequisite and co-requisite for the construction of knowledge, then teachers should try to promote as many positive motivational beliefs as possible, and to do this they should ideally utilize the full range of motivation strategies that are available. The following is a summarizing list of the strategies that have been advocated by the motivation constructs described in the previous section.

In order to enhance student motivation, teachers should:

1. challenge students by setting tasks at a moderate level of difficulty so they can regularly experience success;
2. use novel or discrepant experiences to arouse curiosity;
3. use fantasy;
4. increase the meaningfulness of content and tasks by relating them to the students' lives;
5. use a variety of different types of activities and tasks;
6. allow students to be active participants in the lesson;
7. allow students a realistic level of choice in work partners, activities and task formats;
8. allow students to work individually or collaboratively in situations that do not encourage competition;
9. provide assessment feedback, and use praise that rewards effort and improvement (these should be given privately, to avoid social comparison);
10. model enthusiasm, thinking, dealing with errors, and dealing with challenge; and
11. be supportive, reassuring, and attentive to the students.

Of course, some students may still be motivated even if teachers do not utilize these strategies. Such students may already have high individual interest or well-developed learning goals. However, research suggests that, during the crucial middle school and high school years, these types of students would be in the minority. It is generally agreed that there is a strong downturn in student motivation during middle school (Anderman & Maehr, 1994), particularly in science (Butler, 1999; Tobin, Tippins, & Gallard, 1994). The types of recommendations listed are therefore needed in order to optimize the motivation of all students.

There is thus a range of motivation strategies that could be integrated into classrooms. The following section will examine some models of constructivist-informed teaching and will determine the extent to which these types of strategies have been included in them.

Constructivist-informed Teaching Models

Over the past two decades, a number of authors have proposed models of classroom teaching for science. Some of these models are described in the following—they were chosen to represent a range of approaches to constructivist-informed teaching, but it is recognized that the list is by no means exhaustive. They are presented roughly in chronological order and the authors' references to motivation have been identified. For the purpose of comparison, some of the earlier models (i.e., the early 1980s to the early 1990s) will be described and analysed first, then some recent models (from the late 1990s onwards) will be treated.

Description of Earlier Models

Nussbaum and Novick (1982) were among the first authors to propose a constructivist instructional model for science. They suggested that accommodation could be facilitated in three steps: exposing alternative frameworks by using an "exposing event" that would require students to state their preconceptions and debate them with each other; creating conceptual conflict through the use of a "discrepant event" demonstration that the students cannot explain using their preconceptions; and students search for a solution and one of their proposals will be the desired conception, which is then elaborated upon. The authors argued that the use of discrepant events (in the second step of the sequence) would arouse motivation as well as creating the need for conceptual change. They trialled this technique and found that students were motivated and that conceptual change did occur.

Cosgrove and Osborne (1985) proposed a "generative learning" model in which the teaching sequence consisted of four phases: the *preliminary phase*, in which the teacher ascertains the pupils' views through surveys or other activities; the *focus phase*, in which the pupils' attention is focused on a phenomenon and their ideas about that phenomenon; the *challenge phase*, in which pupils present their views to the group, the teacher presents the scientific view, and they are discussed and compared in order to facilitate accommodation; and the *application phase*, in which the students use the accepted scientific viewpoint to solve a range of problems. The authors stated that motivating experiences would occur in the focus phase but the exact nature of these experiences was not described. However, they did emphasize that, in general, content should be related to real, everyday situations as this may help motivation.

Driver and Oldham (1986) proposed a flexible outline of teaching consisting of five phases: *orientation phase*, in which pupils develop a sense of purpose and motivation for the topic; *elicitation phase*, in which pupils make their ideas explicit through discussion or writing; *restructuring phase*, in which students are exposed to the conflicting views of other students or to conflicting evidence in a "surprise" demonstration, and in which the scientific view is presented by the teacher; *application phase*, in which students apply their new conceptions to a variety of situations, both familiar and novel; and (5) *review phase*, in which students reflect upon their change of ideas. Although the authors stated that pupils would develop motivation during the orientation phase, the source of the motivation was not identified.

Neale, Smith, and Johnson (1990) based their teacher education on a social constructivist perspective, and identified six characteristics of conceptual change teaching: instruction is directed towards contradicting children's mental schemes (i.e., the aim is accommodation); links are made to prior lessons and to children's informal experiences; children's conceptions are elicited through predictions and explanations; children test their prediction in activities that allow them to discover contradictory evidence and contrasting explanations; children present their ideas to each other and debate is encouraged; the children summarize and contrast alternative views. Motivation was not specifically mentioned in this model, but the authors reported that this approach was successful in bringing about conceptual change in children.

Glasson and Lalik (1993) proposed the Language Oriented Learning Cycle, which was a social constructivist modification of the earlier learning cycle designs. It consisted of three phases: *exploration*, in which the students experience cognitive disequilibrium through experiences and concrete materials; *clarification*, in which the learners construct new knowledge to account for their observations; and *elaboration*, in which the students engage in divergent problem-solving. It was intended that during the exploration phase students would participate in stimulating activities designed to engage their curiosity, but otherwise motivation was not an explicit component of this model.

Comments on the Earlier Models

These models were important because they introduced a number of innovative ways to enhance classroom teaching. The techniques included eliciting students' prior conceptions, providing experiences that contrasted or conflicted with misconceptions, then discussion of the advantages of the scientific viewpoint and its application to new situations. However, none of the models included extensive consideration of motivation, and in some cases (Glasson & Lalik, 1993; Neale et al., 1990) motivation was not explicitly mentioned at all. Two of the models (Cosgrove & Osborne, 1985; Driver & Oldham, 1986) included a particular phase that was intended to arouse motivation, but the actual motivating strategies were not described. Two sources of motivation that were identified were discrepant events demonstrations (Nussbaum & Novick, 1982) and relating content to everyday life (Cosgrove & Osborne, 1985). However, in general, it must be concluded that the extent to which motivation was integrated into these earlier models was rather limited. Furthermore, and with the advantage of hindsight, it is possible to identify several features of these models that do not entirely correspond with recent views about motivation. These features are: a step-by-step structure, difficulty levels implied by extended sequences of learning activities, the use of a single experience to arouse motivation, the use of verbal conflict or confrontation, relying on students to "discover" the scientific view, and the "novelty effect" in classroom interventions, as follows.

A step-by-step structure. Most of the models consisted of a structured sequence of steps, which suggests a fairly inflexible learning pathway (the exception was the model by Driver and Oldham, who emphasized that their sequence should be viewed as a flexible outline only). From a motivational perspective, however, there are good reasons to avoid a lock-step approach. Firstly, motivation and learning are idiosyncratic, so learners should be allowed appropriate opportunities for autonomy in the learning process (Bencze, 2000)—teachers need to provide flexibility so students can, to some extent, decide what *they* need to do in order to accomplish learning. Secondly, it is important to vary tasks and formats from day to day, in order to create variety, which is a source of motivation. Avoiding the repetitious use of a structured format is one way to promote variety.

Difficulty levels implied by extended sequences of learning activities. The models typically consisted of carefully designed sequences that need to be followed if learning is to be successful, and in some cases these sequences may take longer than a single lesson to complete. This implies that learning, or accommodation, is going to be a difficult and time-consuming process, and it has been described as such (Pines & West, 1986). From a motivational perspective, however, it is important that learning tasks should not involve a high level of difficulty or an extended amount of time. One of the most powerful sources of intrinsic motivation is challenge. Ideally, accommodation should involve only a moderate level of difficulty for each student, as this is the essence of challenge (Middleton, 2004). It is also important that accommodation should not be time-consuming because successes would then be few and far between. Bandura (1982) argued that regular, short-term successes are a powerful source of self-efficacy. This suggests that students should experience regular feelings of success through being faced with a series of moderate and achievable challenges, preferably on a lesson by lesson basis. The type of success here is success in understanding science concepts, rather than success in passing assessment tasks (although the two should hopefully be related). Thus, if accommodation requires extended sequences of learning activities, then there is the potential for decreased motivation.

The key to the resolution of this problem lies in the basic assumption that accommodation is necessarily difficult. Rather, it could be argued that accommodation is not always difficult. From a very early age children engage in the processes of assimilation and accommodation as they learn about their world. It is something that happens with relative ease, and on almost a daily basis. Although they can develop ideas that are at variance with accepted scientific viewpoints, not all these misconceptions are difficult to change in science classrooms. For example, Palmer (2003) found that accommodation of a biological misconception occurred after a short intervention of only a few minutes. Wandersee et al. (1994) carried out a comprehensive survey of the literature on students’ conceptions and concluded that “Not all alternative conceptions are tenacious. It is important to differentiate between the concepts that might require high-powered conceptual change strategies and those that are equally likely to yield to well-planned, conventional methods” (p. 186).

Thus, a particular student could have some misconceptions that might be hard to overcome, but could have others that would present more moderate levels of difficulty.

If motivation is to be optimized, then students need to be able to experience success in every science lesson. This means that the concepts presented to students should be carefully selected so as to present an achievable level of challenge within the time frame of a single lesson. Concepts with higher levels of difficulty (including those associated with higher levels of abstraction or those associated with strongly-held misconceptions) should not be presented to students until they have developed the conceptual ecology that will allow them to experience success after a few minutes of effort. From a motivational perspective it is therefore preferable to avoid the use of extended sequences of learning activities that take longer than a single lesson to complete, and it should be possible to do this by careful selection of concepts according to their difficulty levels. In fact it could be argued that if a concept does require an extended sequence of experiences before the students understand it, then it is, by definition, too difficult for those students.

The use of a single experience to arouse motivation. In some of the models, motivation depended upon a single experience that was to be included in one particular step or phase. For example, Nussbaum and Novick (1982) included a discrepant event demonstration as the second step of their sequence, and this was intended to arouse motivation as well as create the need for conceptual change. The assumption of this approach is that one interesting demonstration will be enough to arouse motivation that will be maintained until accommodation has been achieved. According to motivational theory, the initial arousal of motivation is certainly possible—research has indicated that situational interest can be aroused by a novel or surprising experience. However, this research (which postdates these earlier models) suggests that although such experiences can arouse interest in the majority of students in the class, their effects are usually relatively transient (Hidi & Harackiewicz, 2000). The extent to which a discrepant events demonstration will maintain student motivation throughout the rest of the lesson is therefore debatable. There is nothing inherently wrong with using a single motivating experience, but it should preferably be supported by other sources of motivation.

The use of verbal conflict or confrontation. According to some models, after students' ideas are elicited they should be confronted with conflicting ideas or conflicting evidence. For example, the "challenge phase" described by Cosgrove and Osborne (1985) required students to present their views for discussion and comparison with the scientific view presented by the teacher. Recent studies have also supported the use of this type of conflict situation (Nussbaum & Sinatra, 2003). In fact, Driver, Newton, and Osborne (2000) proposed that conceptual change mainly occurs through "dialogic argument", in which "different perspectives are being examined and the purpose is to reach agreement on acceptable claims or courses of action" (p.

291). From a motivational perspective, however, there can be potential problems when students present their ideas to the class for scrutiny. If students have their ideas systematically critiqued with evidence of their scientific inadequacy, they may lose confidence in their ability to construct knowledge (Bencze, 2000; Gil-Pérez & Carrascosa-Alis, 1994). Dreyfus, Jungwirth, and Eliovitch (1990) found that bright, successful students reacted enthusiastically to confrontation, whereas unsuccessful students were “characteristically apologetical when confronted with a conflict which, to them, seemed to represent just another failure” (p. 566). It is therefore possible that regular confrontation could reduce motivation as some students experience feelings of failure instead of feelings of success. To some extent it may be possible to alleviate this problem by creating a positive classroom climate in which students’ conceptions are valued and errors are considered a natural part of learning. However, it would be even better if, in addition, future studies are able to develop ways of reducing the level of confrontation in these situations.

Relying on students to “discover” the scientific view. In some models, it was proposed that the scientific view could be elicited from the students themselves as they search for a solution to problems (Neale et al., 1990; Nussbaum & Novick, 1982). However, this may not always have positive effects—Smith, Maclin, Grosslight, and Davis (1997) reported that, although their students “sometimes showed clear signs of being exhilarated by open-ended classroom debates, at other times they were frustrated when the teacher would not simply tell them the right answer or when they had to wrestle with a conceptual confusion” (p. 386). Thus, if students are expected to develop the scientific view themselves, but are unable to do so, then there is the potential for a learning failure rather than a learning success, and motivation could be inhibited.

The “novelty effect” in classroom interventions. Although not all of the authors reported classroom trials of their models, those that did were able to report positive results. For example, Nussbaum and Novick (1982) described two detailed lessons on the particle model of gases and found that seventh-grade students were highly motivated and moved towards a more scientific understanding of the concepts. However, there are reasons to treat these types of results with caution. Any classroom trial of an innovative teaching technique has the potential to artificially enhance student motivation by introducing a source of novelty and variety into the classroom. Most science classes use traditional, teacher-centred techniques so the introduction of a new teaching style could motivate the students simply by virtue of being unusual. This type of problem has been referred to as the “novelty effect” (Gay, 1987). In addition, the teachers involved in the intervention would have been motivated to participate in the study and motivated to attempt new teaching strategies. It would not be unreasonable to suspect that teacher enthusiasm would be fairly high in these situations, and this can also enhance student motivation. These two sources of motivation are artefacts that would have the effect of increasing motivation, and therefore the likelihood of positive learning outcomes, beyond that which might be expected in a more ongoing situation. The influence of these factors should be considered in all classroom trials of innovative teaching techniques.

In summary, the earlier constructivist-informed teaching models contained several features that, according to more recent evidence, could potentially inhibit motivation. These included the use of a step-by-step structure, the difficulty levels implied by extended sequences of learning activities, the use of verbal conflict or confrontation, and relying on students to "discover" the scientific view. In addition, the use of a single experience to arouse motivation, and possible artefacts caused by the novelty effect in classroom interventions, were identified as further issues to be considered.

Description of Recent Models

In 1993, Pintrich et al. stressed the importance of motivation in conceptual change, and their arguments began to inform later views of conceptual change in science (Dekkers & Thijs, 1998; Duit & Treagust, 2003; Hynd, Alvermann, & Qian, 1997; Tyson et al., 1997). The extent to which motivation has been included in more recent models of constructivist-informed teaching is therefore of interest. In the next two sections, several of these models are described and then analysed from a motivational perspective.

Banet and Núñez (1997) designed a teaching sequence centred on attractive or surprising activities that would capture the attention of the students and promote cognitive conflict. It consisted of three phases: *initiation*, in which the programme is explained, students become motivated, and their ideas are elicited; *restructuring of ideas*, in which situations that provoke cognitive conflict are used to reveal the inadequacy of pupils' ideas and encourage the formation of new knowledge; and *application and review*, in which new ideas are shown to be valid and students review the change in their thinking. The authors stated that the students would become motivated during the initiation phase—exactly how this would be done was not explained, but the types of activities suggested included presentation of unusual or thought-provoking situations, as well as concept maps, group work, and discussion. The overall procedure was effective in helping a majority of students to improve their understandings of human nutrition.

Dekkers and Thijs (1998) developed a modified "conceptual replacement" approach to develop students' concepts of force. They argued that many students' misconceptions arose from mistaking the meaning attached to scientific terms such as "force", whereas their actual ideas were in many cases not incorrect, but were limited to a small range of contexts. By using concept refinement and context expansion it should therefore be possible to move students towards a more scientific view. They developed the following teaching sequence:

1. Find a shared meaning of "force" in limited contexts.
2. Refine that partial concept of "force" and expand these contexts until the meaning is no longer shared …

3. Resolve dissonance: compare and find shared meanings, based on the already established agreements. (Dekkers & Thijs, 1998, p. 42)

The authors reported that motivation was aroused through the use of teaching activities that created cognitive dissonance. This model was successful in helping many students to move towards the correct concept.

Hewson et al. (1999) proposed guidelines for teaching for conceptual change. The components were: *ideas*, the ideas of both students and teachers need to be a part of the classroom discourse; *metacognition*, in which students express opinions about ideas; *status*, as some ideas become more acceptable to students and other ideas less acceptable; and *justification*, as the reasons for ideas and status decisions needs to be justified. The authors identified several environmental factors that would help support these guidelines, including a classroom climate of respect for the ideas of others, the teacher as a facilitator of learning, and student willingness to change their views and monitor their learning. These authors did not specifically mention motivation as a factor in teaching for conceptual change.

Blank (2000) proposed a Metacognitive Learning Cycle of four phases. The cycle begins with the *concept assessment* phase, in which students reflect on their science ideas and the status of those ideas (i.e., whether they are intelligible, plausible and fruitful). In the *concept exploration* phase, the students explore phenomena related to the concept. This is followed by the *concept introduction* phase, in which the teacher introduces the main concept in the lesson and the students reflect on any changes in their ideas. Finally, in the *concept application* phase, the students are presented with other examples of the concept and again consider the status of their ideas. Blank found that students taught using this approach did not gain a greater content knowledge but there was some evidence of more permanent restructuring of understandings. Motivation was not mentioned as a factor in this model.

She (2004) proposed a Dual-Situated Learning Model consisting of six stages:

1. Examining attributes of the science concept.
2. Probing students' misconceptions of the science concept.
3. Analysing which mental sets students lack.
4. Designing dual-situated learning events.
5. Instructing with dual-situated learning events.
6. Instructing with challenging situated learning event. (p. 147)

The dual-situated learning event implemented in the fifth step was an experience designed to "create dissonance with students' original beliefs of science concept, and provide a new mental set for them to achieve a more scientific view" (p. 147). The author argued that one of the purposes of dissonance was to create motivation, as it would arouse students' curiosity and interest. She trialled the Dual-Situated Learning Model using a series of carefully designed demonstrations that were administered in individual interviews. It was found that the majority of the students experienced radical conceptual change in their understanding of heat transfer.

Comments on the Recent Models

As far as motivation is concerned, the more recent models showed some improvements in comparison with the earlier models. In particular, some of the features that were identified as potentially inhibiting to motivation have been de-emphasized in two of the recent models. Dekkers and Thijs (1998) minimized the use of conflict or confrontation, by refining and extending students' current conceptions. Also, Hewson et al. (1999) avoided the use of a step-by-step structure by proposing "guidelines" for conceptual change. However, in other respects, there has been relatively little change. None of the recent models explicitly integrated motivation throughout the full sequence. Some did not mention motivation at all (Blank, 2000; Hewson et al. 1999), whereas in others it was dependent upon experiences involving dissonance (Dekkers & Thijs, 1998; She, 2004). Furthermore, most of the recent models still comprised extended, step-by-step sequences of learning activities that, as already explained, could potentially have negative effects on motivation. Thus, it appears that motivation has still received limited recognition in recent models of constructivist-informed teaching.

In defence of these models, it could be argued that it is not necessary to explicitly consider motivation or its sources. For example, several of the models have demonstrated reconstruction of knowledge by students, so motivation could be *assumed* to be inherent in those models, as motivation is necessary for construction of knowledge. Similarly, it might be argued that, as constructivist classrooms are relatively student-centred, then motivation can be assumed to be fairly high, so there is no need to explicitly consider it in the models. However, neither of these arguments is convincing. Firstly, the novelty effect can artificially raise students' participation and achievement, so evidence of effectiveness in trials or interventions should be treated carefully. Secondly, constructivist-informed teaching has not always resulted in high motivation. Banet and Núñez (1997) found that their programme was not successful in maintaining the interest of about one-third of their 13-year-old and 14-year-old students. Similarly, Lee and Brophy (1996) investigated teaching that was guided by a conceptual change approach and found that it failed to motivate half of the sixth-grade students in their study. These studies suggest that motivation can still be problematical in constructivist-informed classrooms, so one should not assume that it is inherent. Consequently, future models of constructivist-informed teaching do need to explicitly consider motivation and the factors that may positively or negatively impact upon it.

Some examples of negative factors have already been described in this article, but it is important to emphasize that constructivist-informed teaching models do have several features that could positively impact upon motivation. These include teaching techniques such as eliciting students' views, clear explanations of the scientific viewpoint, hands-on activities, and application to real life, as follows.

Eliciting students' views. Hewson et al. (1999) reported a number of studies showing that elicitation of students' views can be effected by using tasks such as preinstructional quizzes, interviews, group posters, questions, and concept mapping. Morrison and Lederman (2003), however, found that science teachers who did try to elicit students' views used a much more limited repertoire of techniques, focusing mainly on questioning and discussion. From a motivational perspective, the elicitation of students' ideas should usually be a positive experience, as it can promote active participation in the lesson, but some methods may be more motivating than others. On one hand, for example, there is evidence that science students can be motivated by class discussions in which they express their ideas (Hand, Treagust, & Vance, 1997); but, on the other hand, the use of quizzes and diagnostic tests may be more problematical. Harlen and Crick (2003) reported that testing may have a negative effect on student motivation, especially for weaker students who may "become overwhelmed by assessments and demotivated by constant evidence of their low achievement" (p. 196). These authors focused mainly on summative rather than diagnostic assessment, but one of the main outcomes of their study was that relatively little is known about the impact of various types of testing on motivation. In the light of this, it would seem important that quizzes and other types of diagnostic testing should be further investigated to determine their motivational impact.

Presenting the scientific viewpoint. Many constructivist-informed teaching models have included a phase in which the teacher presents the scientific view to the students (Blank, 2000; Cosgrove & Osborne, 1985; Driver & Oldham, 1986). Driver et al. (2000) have emphasized that students need opportunities to hear explanations given to them by experts, which can include teachers, but also other sources such as books and computer programs. It is difficult to evaluate the potential motivational effects of techniques such as teacher explanation or the reading of science text. Certainly, the repetition caused by overuse of these techniques has been associated with reduced motivation (Eichinger, 1997). However, there is some evidence that, when used in balanced combination with other techniques, clear explanations can enhance student motivation by facilitating success in understanding science concepts (Palmer, 2001). Computer programs can also be used to present scientific ideas, and these have the advantage of allowing students to change variables in problems, and receive immediate feedback on the consequences (Tao & Gunstone, 1999). Computer simulation is motivating to students (Terrell & Rendulic, 1996) and this is possibly due to their ability to create fantasy, which is an important source of intrinsic motivation. Computers allow the creation of imaginary situations such as frictionless worlds—Hennessy et al. (1995) trialled a computer-augmented strategy with 12–13 year olds and reported the following comments of one teacher:

> I think it gave leeway for them to appreciate that there was a real world in which there were certain restrictions, rules, laws that were obeyed. And that in an imaginary situation, a magic world, those laws weren't obeyed. I think it actually reinforced that the real world has got laws; also, it was fun for them which I think is a very important part of the whole thing. (p. 203)

Use of hands-on activities. Constructivist models have advocated the use of hands-on activities for a number of purposes: to generate students' ideas at the beginning of a unit (Nussbaum & Novick, 1982); to present students with real-world problems that can provide a basis for discussion (Lee & Brophy, 1996; Nussbaum & Novick, 1982); to collect evidence in order to evaluate alternative ideas (Driver & Oldham 1986); to explicitly test students' assumptions, discover contradictory evidence, and promote cognitive conflict (Banet & Núñez, 1997; Neale et al., 1990); and to provide examples of a range of contexts to which students might apply their ideas (Beeth & Hewson, 1999). Weaver (1998) provided evidence that hands-on science activities create motivation and interest as long as they are not verification exercises. This motivation probably arises because they involve active student participation and also provide an opportunity for students to collaborate. In addition, there are some ways in which their motivational effects can be further enhanced. Martinez (1992) modified hands-on activities by introducing fantasy scenarios, and found that these were particularly effective for experiments that previously had little intrinsic appeal. Also, Palmer (2001) found that the use of everyday materials rather than specialized scientific equipment increased situational interest by making the hands-on activities more relevant to real life.

Application of concepts to real life. According to most models of constructivist-informed teaching, students should have opportunities to apply their learned ideas to a range of problems or situations. For example, Banet and Núñez (1997) described an "application phase" that was intended to consolidate and validate changes in the students' thinking. From a motivational perspective, it is important that these experiences should focus on the application of the concept to real life situations. This would have the potential to enhance task value beliefs—students may perceive the concepts as relevant and valuable because they help them to understand the real world (Zusho et al., 2003).

In summary, the more recent models of constructivist-informed teaching are broadly similar to the earlier models in giving only limited recognition to motivation. The models typically contain some features that have the potential to inhibit motivation, but they also utilize a range of teaching techniques that have the potential to enhance it. If motivation is to be optimized in constructivist classrooms, then the potentially inhibiting factors should be avoided as much as possible, and preference should be given to the techniques that are potentially enhancing. At this stage, it should be pointed out that these techniques may not always be effective in promoting scientific viewpoints—strategies such as cognitive conflict and peer group argumentation have been questioned by a number of authors (Chinn & Malhotra, 2002; Limón, 2001; Windschitl, 2001)—but a comprehensive analysis of each of them is beyond the scope of this paper, so instead the focus has been on their potential to motivate. The following section will explain how this process, of evaluating the motivational potential of specific instructional techniques, can be incorporated into a model of constructivist-informed teaching.

A Motivational Model of Constructivist-informed Teaching

According to constructivist theory, learning is an active process requiring effort, so students need to be motivated to make that effort. In a constructivist classroom, teachers should therefore aim to arouse students and maintain their motivation at optimum levels throughout the learning process. However, motivation by itself only means that students are willing to engage in learning—it does not ensure that they will develop scientifically acceptable knowledge structures (Pintrich et al., 1993). Strategies for motivation therefore need to be integrated with teaching techniques that can reduce the status of students' misconceptions and increase the status of scientific concepts. However, this approach has not been explicitly adopted by extant models of constructivist-informed teaching, so the following model is presented as an alternative.

This model emphasizes the importance of motivation as a mediator for learning. Although it contains three sections, these are not steps in a learning sequence, but instead are components of the learning environment. The three components are:

1. *Selection of concepts that represent appropriate challenge*. Motivation will be optimized when students experience success on a lesson by lesson basis, so they should not be allowed to attempt accommodation that requires extended periods of time and struggle. Extended sequences of step-by-step procedures should therefore not be required. Teachers should select concepts that represent achievable challenge considering the conceptual ecologies (including the epistemological and ontological beliefs) of the students in the class. Although students should ideally experience success in every lesson, this should not be interpreted as meaning that students should attempt to learn a new concept in every lesson. It is important that students have multiple opportunities to practice using the concepts they have learnt, in order to establish them in long-term memory (Nuthall, 1999).
2. *The use of "dual-purpose" teaching techniques*. The ideal teaching techniques will be those that not only contribute towards the development of scientifically acceptable conceptions, but also have the potential to motivate. As often as possible, teachers should select techniques that have such a dual purpose. According to the arguments already presented in this paper, these might for example include class discussions, clear teacher explanations, appropriate hands-on activities, computer simulations, and application to real-life contexts. Conversely, any teaching technique that could have negative effects on motivation should be avoided.

   Teaching techniques should not be presented in any particular sequence or series of steps, but should be selected on a case by case basis and in various combinations according to what the research says about their effectiveness in directing students towards more scientific ways of thinking *and* their ability to motivate. One example of a combination of techniques was investigated by Chinn and Malhotra (2002) for the topics of heat and motion. They found that a combination of teacher explanation and hands-on activities promoted conceptual change, because the explanations could be used to guide students' observations in the activities. Other combinations that have been successfully trialled include a small discussion/laboratory approach (Christianson & Fisher, 1999), peer group collaboration/computer simulation (Tao & Gunstone, 1999), and computer simulation/written material/practical activity (Hennessy et al., 1995). A variety of motivational factors may operate in these relatively complex situations. For example, collaboration can be source of motivation, and Tao and Gunstone reported high on-task engagement when students worked together in peer groups at the computer. In addition, these combination techniques have the potential to enhance motivation by creating variety, as students move from one activity to another. However the motivational impact of these techniques has not always been investigated, and the extent to which students in such studies have been artificially motivated by the novelty effect is still an issue of concern. There is clearly a need for future studies to report on not only the effectiveness of techniques for promoting scientific ways of thinking, but also for their ability to motivate students in ongoing classroom situations.

It is also important that teachers should not place over-reliance on any one technique. Even highly motivating experiences such as discrepant events demonstrations can become monotonous to students if they are overused (Loughran, Northfield, & Jones, 1994) so teachers should choose a variety of techniques from day to day and week to week. For example, there are several ways in which students' views can be elicited. Indeed, for any aspect of teaching, it is important that teachers have a range of techniques at hand in order to create variety, which is itself a source of motivation.

3. *A classroom climate that encourages positive motivation beliefs*. Teachers should not depend only on having an array of interesting teaching techniques to maintain motivation. A range of other classroom factors should be put in place to encourage positive motivational beliefs among the students. These include that students should regularly be given choice in task formats and work partners, competitive situations should be avoided, the teacher should praise effort and improvement, the teacher should express confidence in the students' ability to work at a higher level, the teacher should provide extensive assessment feedback that is given privately rather than publicly, the teacher should model enthusiasm and how to deal with challenges, the teacher should emphasize the relationship of the work to the students' lives, and the teacher should be supportive, reassuring, and attentive as students participate in the learning process. The effect of these strategies will be to complement the interest and involvement that is generated by the dual-purpose teaching techniques.

Concluding Comments

Motivation is a prerequisite and co-requisite for learning, so the essence of a constructivist-informed classroom is that it is one in which the teacher explicitly plans strategies for student motivation and integrates these at all stages of the learning process. On this basis, three components have been identified as necessary for constructivist-informed teaching: selection of concepts that represent appropriate challenge, without the need for extended sequences of learning activities; the use of dual-purpose teaching techniques, which have been shown to promote scientific ways of thinking as well as motivation; and a classroom climate that encourages positive motivation beliefs.

In recent years, our understanding of student motivation has developed to the point where it is possible to identify a range of classroom strategies that have the potential to enhance motivation. Unfortunately, however, confirmatory evidence of their effectiveness in science classrooms is still very scant. For example, the potentially powerful construct of situational interest has had very little trialling in school science classrooms. The arguments presented in this paper should be interpreted with this limitation in mind.

Finally, one of the main aims of educational research should be to inform classroom practice. However, it appears that research on constructivism has not generally been transferred into science classrooms (Duit & Treagust, 2003; Rodriguez, 1998). Instead teachers have been interested in finding ways to motivate their students (Rodriguez, 1998; Sánchez & Valcárcel, 1999). The arguments presented in this paper would indicate that there is a very close link between constructivism and motivation, so it is possible that an emphasis on this link may help to facilitate the willing acceptance of constructivism by science teachers.

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