Constructivism in Theory and Practice: Toward a Better Understanding

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Although constructivism is a concept that has been embraced my many teachers over the past 15 years, the meanings that are attached to this term are varied and often inadequately understood. Teachers need to have a sound understanding of what constructivism means to evaluate its promise and to use it knowledgeably and effectively. This paper explicates some of the theoretical background of constructivism and then presents a detailed example in which a traditional classroom lesson and a constructivist version of the same lesson are described and analyzed. Also discussed are pervasive myths and important instructional issues of this widely advocated and increasingly popular philosophical framework for teaching across the entire K-12 curriculum.

Introduction

Teachers' personal theories of learning have long been viewed as having considerable influence on virtually all aspects of teachers' decisions about instruction. Not only one's expectations for what learning outcomes are to be valued and sought, but also how one plans (i.e., organizes, structures and sequences) instruction is directly impacted by one's beliefs about learning. In addition, teachers' views of learning guide them as they make decisions about desirable means of implementing and assessing instruction. It is popular today to speak of paradigm shifts, and certainly major conceptual changes do occur in virtually all fields of study. Paradigm shifts bring new perspectives, new conceptualizations and new ways of thinking about a topic, large or small. An important area of study in the philosophy of science is what is referred to as scientific revolutions. Two examples from the natural sciences are the dramatic scientific revolution ushered in by Copernicus' conception of the relationship between the sun and earth, and the revolutionary propositions of Darwin's (though less universally accepted, even today) theory of evolution.

Kuhn?

When a novel conception is introduced it always elicits great resistance. Even as a transformation in general thinking and attitudes develops more support and adherents, there will continue to be resistance to the challenge to the existing order, the comfortable, existing ways of viewing the world. For example, the ideas of Galileo and Copernicus were met with disdain, anger and rejection. But, of course, with time, the established physical order of the universe did become accepted and the earlier views came to be seen as the quaint notions of an earlier uninformed era. Ultimately most if not all the ideas of the older paradigm will be discarded; and this is as it should be when the scientific evidence unequivocally points to a more adequate explanation of certain phenomena. As a new paradigm gains respect and acceptance, a gradual and sometimes relatively rapid process of intellectual disassociation occurs. People take flight from the earlier, now prosaic and apparently inadequate ways of viewing the world with a lens that is no longer capable of clearly capturing "truth". A new, fresh conceptual rendering of a topic, phenomenon or means of investigation is promoted. A new theory is offered to supplant an older theory (Kuhn, 1970).

Conceptual change in the social sciences differs somewhat from that in the natural sciences (Thagard, 1992) in large part because the social sciences do not yet have a coherent unifying theory. Thus major conceptual change within a field may better typify significant shifts in the disciplines of the social sciences and education. Nonetheless, the adoption of different theoretical models and application of different assumptions about the nature of human learning has resulted in raging controversies and paradigm shifts within psychology this century (the ascendancy of and subsequent decline of behaviorism; the rise of cognitivism) and in substantial reconceptualizations of philosophy and pedagogy in education.

The field of education has undergone a significant shift in thinking about the nature of human learning and the conditions that best promote the varied dimensions of human learning. As in psychology, there has been a paradigm shift in designed instruction; from behaviorism to cognitivism and now to constructivism (Cooper, 1993). Certainly one of the most influential views of learning during the last two decades of the 20th century is the perspective known as constructivism. Although by no means an entirely new conceptualization of learner and the process of learner (roots can be traced to John Dewey and progressive educators, to Piaget and Vygotsky and to Jerome Bruner and discovery learning), constructivist perspectives on learning have become increasingly influential in the past twenty years and can be said to represent a paradigm shift in the epistemology of knowledge and theory of learning. Fundamental conceptual changes in perceptions of teaching are clearly reflected in the guidelines of the National Council of Teachers of Mathematics and the American Association for the Advancement of Science. The increasingly prevalent literature-based approaches to reading and process approaches to writing both share constructivist roots (McCarthy, 1990); and perusal of current school textbooks reveals the influence of constructivist views of learning (Thompson, McLaughlin, & Smith, 1995). Without question, there are widespread indicators that constructivist views of learning have captured the current zeitgeist in today's educational arena.

The term constructivism most probably is derived from Piaget's reference to his views as "constructivist" (Gruber & Voneche, 1977), as well as from Bruner's description of discovery learning as "constuctionist" (1966). Other terms are also used to refer to constructivist views of learning, including: generative learning (Wittrock, 1985; situated learning and authentic instruction (Brown, Collins, & Duguid, 1989), postmodern curricula (Hlynka, 1991); and educational semiotic (Cunningham, 1992). Even though constructivists cannot be adequately represented by a single voice or an entirely universal point of view, there is a conception of learner and learning that is unmistakable in its central tenets and in its divergence from an objectivist tradition of learning theory based on either behaviorism (associationistic models of learning) or cognitivism (the cognitive science of information processing representations of learning).

Objectivism posits that knowledge of the world results from experiencing our world and representing it in an increasingly accurate way. Knowledge is believed to exist independently of the learner, and then to become internalized as it is transferred from its external reality to an internal reality of the learner that corresponds directly with outside phenomenon. Both behavioral and cognitive information-processing theories subscribe to this perspective from the objectivist tradition (Driscoll, 1994). Constructivism proposes that learner conceptions of knowledge are derived from a meaning-making search in which learners engage in a process of constructing individual interpretations of their experiences. The constructions that result from the examination, questioning and analysis of tasks and experiences yields knowledge whose correspondence to external reality may have little verisimilitude. However, to the degree that most of our learning is filtered through a process of social negotiation or distributed cognition (Brown, A. L., Ash, D., Rutherfored, M., Nakagawa, K., Gordon, A. and Campione, J. C., 1995); Brown & Campione, 1994; 1993; Salomon, 1993; Confrey, 1990), generally shared meanings, tend to be constructed. Even von Glaserfeld (1990) P. 87, widely recognized as a radical constructivist has commented that, "No individual can afford not to establish a relative fit with the consensual domain of the social environment."

But how do these views alter teachers' conceptions of the teaching-learning process? How is constructivism translated into practice and what should teachers and prospective teachers know about the theory and its educational implications? In this paper we will examine the critical aspects of the constructivist perspectives on learning and instruction and identify those essential understandings for preservice teachers to acquire. We begin with a brief exposition of the fundamental concepts and principles of constructivism, followed by a portrait of a very ineffective hypothetical middle grades classroom in which a poorly executed lesson will serve as a foil for critiquing instruction from a constructivist perspective. To further exemplify the instructional aspects of constructivism, a detailed example of instruction illustrating constructivist pedagogy will be presented. Myths that have developed concerning tenets of constructivism and pedagogical practices derived from this perspective will be illuminated and challenged and detailed analysis will be devoted to certain key instructional issues about which any model of instruction must address. The paper will conclude with a synthesis and evaluation of constructivist inspired instructional practices.

The Constructivist View of Human Learning

Constructivism is an epistemological view of knowledge acquisition emphasizing knowledge construction rather than knowledge transmission and the recording of information conveyed by others. The role of the learner is conceived as one of building and transforming knowledge. But what does it mean to construct knowledge? Within constructivism there are different notions of the nature of knowledge and the knowledge construction process. Moshman (1982) has identified three types of constructivism: exogeneous constructivism, endogenous constructivism and dialectical constructivism.

In exogenous constructivism, as with the philosophy of realism, there is an external reality that is reconstructed as knowledge is formed. Thus one's mental structures develop to reflect the organization of the world. The information processing conceptualizations of cognitive psychology emphasize the representation view of constructivism, calling attention to how we construct and elaborate schemata and networks of information based on the external realities of the environments we experience.

Endogenous constructivism or cognitive constructivism (Cobb, 1994; Moshman, 1982) focuses on internal, individual constructions of knowledge. This perspective, which is derived from Piagetian theory (Piaget 1977, 1970), emphasizes individual knowledge construction stimulated by internal cognitive conflict as learners strive to resolve mental disequilibrium. Essentially, children as well as older learners must negotiate the meaning of experiences and phenomena that are discrepant from their existing schema. Students may be said to author their own knowledge, advancing their cognitive structures by revising and creating new understandings out of existing ones. This is accomplished through individual or socially mediated discovery-oriented learning activities.

Dialectical constructivism or social

constructivism (Brown, Collins, & Duguid, 1989; Rogoff, 1990) views the origin of knowledge construction as being the social intersection of people, interactions that involve sharing, comparing and debating among learners and mentors. Through a highly interactive process, the social milieu of learning is accorded center stage and learners both refine their own meanings and help others find meaning. In this way knowledge is mutually built. This view is a direct reflection of Vygotsky's (1978) sociocultural theory of learning, which accentuates the supportive guidance of mentors as they enable the apprentice learner to achieve successively more complex skill, understanding, and ultimately independent competence.

The fundamental nature of social constructivism is collaborative social interaction in contrast to individual investigation of cognitive constructivism. Through the cognitive give and take of social interactions, one constructs personal knowledge. In addition, the context in which learning occurs is inseparable from emergent thought. This latter view known as contextualism in psychology becomes a central tenet of constructivsm when expressed as situated cognition. Social constructivism captures the most general extant perspective on constructivism with its emphasis on the importance of social exchanges for cognitive growth and the impact of culture and historical context on learning.

"While there are several interpretations of what [constructivist] theory means, most agree that it involves a dramatic change in the focus of teaching, putting the students' own efforts to understand at the center of the educational enterprise" (Prawat, 1992). Thus despite the differences sketched above, there is important congruence among most constructivists with regard to four central characteristics believed to influence all learning: 1) learners construct their own learning; 2) the dependence of new learning on students' existing understanding; 3) the critical role of social interaction and; 4) the necessity of authentic learning tasks for meaningful learning (Bruning, Royce, & Dennison, 1995; Pressley, Harris, & Marks, 1992).

For the learner to construct meaning, he must actively strive to make sense of new experiences and in so doing must relate it to what is already known or believed about a topic. Students develop knowledge through an active construction process, not through the passive reception of information (Brophy, 1992). In other words, learners must build their own understanding. How information is presented and how learners are supported in the process of constructing knowledge are of major significance. The preexisting knowledge that learners bring to each learning task is emphasized too. Students' current understandings provide the immediate context for interpreting any new learning. Regardless of the nature or sophistication of a learner's existing schema, each person's existing knowledge structure will have a powerful influence on what is learned and whether and how conceptual change occurs.

Dialogue is the catalyst for knowledge acquisition. Understanding is facilitated by exchanges that occur through social interaction, through questioning and explaining, challenging and offering timely support and feedback. The concept of learning communities has been offered as the ideal learning culture for group instruction (Brown, 1994; Brown and Campione, 1994). These communities focus on helping group members learn, by supporting one another through respectful listening and encouragement. The goal is to engender a spirit and culture of openness, exploration and a shared commitment to learning.

Situated cognition or learning is a concept advocated in social constructivist approaches and is a natural extension of the importance attached to the context, social and cultural, in which learning is believed to be born. Knowledge is conceived as being embedded in and connected to the situation where the learning occurs. As a consequence, thinking and knowledge that is constructed are inextricably tied to the immediate social and physical context of the learning experience. And what is learned tends to be context-bound or tied to the situation in which it is learned (Lave & Wenger (1991). Evidence for the situational nature of learning can be seen in numerous cases where students' school learning fails to transfer readily relevant tasks outside of school. Brown, Collins,

& Duguid (1989) chronicle how people can acquire rather sophisticated mathematical operations in one setting and yet be quite unable to apply those same operations in another setting.

Just how teachers and peers support and contribute to learning is clarified by the concepts of scaffolding, cognitive apprenticeship, tutoring and cooperative learning and learning communities (Brown, 1994; Rogoff, 1998). Cognition is viewed as a collaborative process and modern constructivist thought provides the theoretical basis for cooperative learning, project or problem based learning and other discovery oriented instructional approaches, all of which appeal to the powerful social nature of learning. As students are exposed to their peers' thinking processes, appropriation of others' ideas and ways of thinking is possible. Therefore, constructivists make extensive use of cooperative learning tasks, as well as peer tutoring, believing that students will learn more readily from having dialog with each other about significant problems.

A second key concept derives from Vygotsky's concept of zone of proximal development (Kozulin, 1986). When children work on tasks that cannot be accomplished alone but can be successfully completed with the assistance of a person competent in the task, they are said to be working within their zone of proximal development. Children working in cooperative groups will generally encounter a peer who possesses a slightly higher cognitive level, one within the child's zone of proximal development.

The concept of cognitive apprenticeship is analogous to that of apprenticeships in many occupations where one learns on the job by closely working with a master. The master models behavior and gives feedback and gradually allows the novice increasing opportunity to independently exercise the skills of the profession. A substantial aspect of the learning is the socialization into the norms and behavior of the profession. The experience of teachers and physician interns demonstrates the shadowing and modeling that occurs during this critical period in the development and induction into these professions. More generally, one can say that a cognitive apprenticeship relationship exists between teachers and students to the extent that teachers provide scaffolding or mediate learning for students. At the same time that students are given complex, authentic tasks such as projects, simulations and problems involving community issues, they are also given sufficient assistance to achieve the desired outcomes.

An important aspect of teacher guidance relates to the constructivist notion of generative learning. Since constructivists believe that the learner must transform or appropriate whatever is learned, one can say that all learning is discovered. To appropriate new understandings from one's social environment and to become an efficient maker of meaning requires the adoption of specific intellectual skills, ones that should be modeled from more competent adults and peers. Thus generative learning strategies (learning-to-learn) may be explicitly taught to students or may be discovered by students as they are trying to find strategies for solving problems. For example, students have been guided to generate their own questions and summaries and analogies during reading (King, 1992a; Kourilsky & Wittrock, 1992; Wittrock, 1991), and while listening to lectures (King, 1992b). Reciprocal teaching (Palincsar & Brown, 1984) is a successful method for teaching reading comprehension in which metacognitive skills, including question generation, prediction and summary are taught through teacher modeling, followed by student enactment of the same metacognitive behaviors. The goal is to encourage self-regulated learning, by helping learners develop effective learning strategies and knowledge of when to use them.

The types of tasks that are selected for students to engage in (complex, problem-based, real-life) reveal the emphasis of constructivists on a top-down view of instruction. Students are intentionally confronted with complex tasks that can only be performed with a teacher's guidance and that create an immediate need to develop relevant skills. When students are faced with the task of writing a letter to the county commissioners, they must begin to develop the necessary grammar, spelling, and punctuation skills. So, students learn what they need to know in order to figure out how to accomplish authentic but, difficult tasks at the upper range of their zone of proximal development.

The more traditional approach to instruction, a bottom-up strategy, involves isolating the basic skills, teaching these separately and building these incrementally before tackling higher order tasks. This is an essentially objectivist and behavioral approach to instruction, although cognitive information processing views often lead to similar instructional practices. Constructivists turn this highly sequential approach on its head. Instead of carefully structuring the elements of topics to be learned, learning proceeds from the natural need to develop understanding and skills required for completion of significant tasks. Learning occurs in a manner analogous to just in time manufacturing, where raw materials are received just prior to their use rather than held in expensive inventories. As Fosnot (1996) puts it,

"Constructivism is fundamentally nonpositivist and as such it stands on completely new ground -often in direct opposition to both behaviorism and maturationism. Rather than behaviors or skills as the goal of instruction, concept development and deep understanding are the foci; rather than stages being the result of maturation, they are understood as constructions of active learner reorganization." (p. 10).

We have outlined the major concepts and theories that comprise the foundational elements of constructivism. The picture that we have sketched provides a representative, though necessarily incomplete view of the central features of constructivist theory. Naturally, the reader is invited to explore further the substantial psychological and philosophical underpinnings of constructivism. Now we turn our attention to the instructional dimensions and classroom ecology of teaching imbued with constructivist educational philosophy. To accomplish this, we will present a classroom scenario that will serve as a foil to compare and contrast significant aspects of constructivist approaches to teaching with more traditional approaches. In this way we hope to highlight the typical thought processes and likely practices of the constructivist educator and to illustrate how pedagogy is linked to theory.

A Brief Look at a Typical Classroom Lesson

There are twenty-five students in Ms. Blake's ninth grade science class, comprised of a heterogeneous mix of students who vary widely in their knowledge, intellectual abilities, competence for independent learning and basic skills of writing, reading, arithmetic spelling. The students are seated in neat rows in front of the blackboard and the teacher conducts the lesson while standing at the front of the classroom. After most whole class lessons, students either have short quizzes or individual worksheet assignments to firm up and assess what they were expected to learn from the lesson(s).

The classroom environment seems pleasant, for the room is clean and orderly with science posters prominently displayed, leaving no doubt that science is taught here. During class the students are not badly behaved, even though disruptions are certainly not uncommon. The less competent students often fail to pay attention during lessons; daydreaming and talking can be observed and occasionally distracting or even pestering other students during lessons. Ms. Blake uses various strategies to alter these unproductive and often-disruptive student behaviors, and she regularly asks for them to be quiet and to "listen up."

In her interactions with her students, she is more likely to notice, to call on, and to praise the students who most frequently give "good answers." She gives easier and shorter assignments to students who are less likely to get it and pays even less attention to the details of their efforts. Results of standardized achievement test scores reveal that the less successful students are not making good progress in the mastery of basic content of the science curriculum, and there is corroborating evidence to indicate that they are falling further behind their classmates in other areas as well.

The following lesson illustrates how instruction typically occurs in Ms. Blake's class. The objective for this lesson is to. understand the difference between a parallel and a series circuit, a common 9th grade physical science objective that is useful to master before high school physics.

Ms. Blake drew a complete circuit on the overhead projector and told the students to listen carefully as she described the features of a complete circuit. Her example compared a series with a parallel circuit. Ms. Blake traced the path of the electrons in both drawings and pointed out what would happen in the series circuit if one of the bulbs were to burn out. She identified the major differences between the two wiring schemes. Then she asked a few students to come to the overhead and mark the point on the circuit where resistance and key connections were necessary. To convey the predictive utility of parallel and series circuits, she demonstrated how one could determine which wiring system was used in their classroom by removing one of the florescent light bulbs. At this point in the lesson, students were told to draw and label a parallel and a series circuit in their notebooks.

Following the demonstration, students were placed into groups where they were given wires, batteries and bulbs and instructed to build a series and a parallel circuit just like the one shown on the overhead. They were instructed to work together and record their results on their worksheet. Ms. Blake surveyed the room as the students began to work. In each of the groups, one or two students actually connected the wires while the other three members of the group either occasionally looked on or chatted amongst themselves. Students worked on the task for 15 minutes and then as the period came to a close they were given a homework assignment that required them to identify series and parallel circuits from several examples.

Analysis of Ms. Blake's Class from a Constructivist Perspective

From a constructivist perspective, there are four aspects of this lesson that are deficient. The first problem concerns the arrangement of the physical and social environment of the classroom. The physical and social environment of Ms. Blake's classroom communicates implicitly to students the idea that the teacher is the center of all activities in the classroom. The message is also conveyed that social interaction is expected to happen primarily between the teacher and students, and that she is the sole source of information.

As with any social system, communication in Ms. Blake's classroom is not limited to oral and written language as its only system of conveying meaning. Objects, gestures, images and architecture also contribute importantly to learners' construction of meaning in Ms. Blake's classroom. The desk arrangement, for example, transmits the message that the most important activities are those of the teacher and they occur at the front desk. It also informs students of the expectations that students attend exclusively to what the teacher says and does, stay in their in seats, work by themselves and avoid talking to one another.

From a constructivist perspective, this physical and social environment is less conducive to learning because it discourages students from interacting with one another. Students' thinking is narrowed to what the teacher asks and what she considers to be a correct response. Instead of being encouraged to ask questions, the role of the student is to answer questions. This leads students who are not confident that they know the right answers to minimize their participation in class. It also requires students to comply with the social rules that are set by the teacher (the authority), rather than actively participate in establishing social rules and hold themselves accountable for keeping them.

The second issue relates to the roles that students and Ms. Blake play during her instruction. While Ms. Blake is very busy putting up circuits on the overhead projector, describing the features of parallel and series circuits, and demonstrating, with examples how to communicate and predict what would happen if one of the bulbs burned out, the students are passively listening — if we assume they are in fact listening. During her presentation, Ms. Blake has no way of knowing what students as a group know about the subject matter, what perceptions or misconceptions they bring to the task, or how well they understand the information being presented to them (not to mention individual differences among students). In other words, except for the relatively few questions asked by Ms. Blake (who does most of the talking), and answers that are most likely given by students who know the right answers, there is little opportunity for adjustment for the instruction to students' level of understanding. Consequently, as the case suggests, while Ms. Blake is very active in thinking and providing information, students are engaged in a passive learning and thinking role.

It must be acknowledged that Ms. Blake makes an attempt, however modest, to enable her pupils to engage in peer oriented learning when she asks students to work in groups to construct a series and a parallel circuit. In this instance the students are not challenged to construct meaning but rather to replicate with real objects the circuits she had drawn on the overhead. It is desirable to challenge students with tasks that they must complete through meaningful dialogue with peers as they strive to socially construct meaning. Unfortunately, Ms. Blake has neither determined what misconceptions about wiring the students hold, nor prepared the students for group learning, nor adequately structured the task. She also does not closely monitor student behavior or interact with her students as they work. As a consequence, this lesson includes only a perfunctory group task rather than a skillfully implemented cooperative learning task.

The last concern involves the way Ms. Blake treats the science content. Although Ms. Blake provides an explanation of a parallel and a series circuit (by placing them on the overhead projector and describing the essential differences) and uses examples to demonstrate how to make predictions from both circuits, what are her students learning? For many students it is likely that they have learned to recall only the procedures for drawing the circuits — a learning achieved as they draw their own circuits on the worksheet and complete their homework assignment. Whether or not students have come to understand the concept of parallel and series circuits and are able to use it to solve their daily and real world problems is unclear. In fact, even though the students have practiced remembering the procedures and can use the words parallel and series, it is unlikely they will be able to apply the concepts and rules in problem situations. Thus the necessary and sufficient conditions for acquiring the concept, rule and problem solving learning are not present in this lesson, and Ms. Blake has failed to assess students' learning outcomes adequately.

Ms. Blake's Classroom: A Constructivist Version

Teacher Roles, Student Roles, and Interactions

Ms. Blake's ninth grade classroom can be distinguished from other classrooms both in looks and sounds. Upon walking down the corridors we hear from the classroom at the end of the hallway an array of voices and sounds like buzzing, chattering, an occasional "I got it" and sometimes expressions of frustration. Upon entering the classroom, we see clusters of students working with various objects. In fact, if it were not for the age of Ms. Blake, it would be hard to identify who the teacher is in this classroom. Ms. Blake is talking with one of the groups near the doorway and says, "Why did you select that arrangement and place the bulb there? Will it work if attached in another way? Talk about it in your group and I will get back to you shortly." She then moves to the next group, sits down with them and watches as students continue working with batteries and bulbs in the center of their cluster. They don't seem to notice Ms. Blake and keep on talking with each other. She is smiling as she observes them.

If we enter this classroom with our traditional preconceived notions that classrooms of learning should be ordered, systematic and quiet, we will miss the dynamic learning that is occurring in this and other classrooms that are structured for cooperative learning and from a constructivist philosophy. In fact, we may even make the egregious error of thinking that Ms. Blake has lost control of her class and her students. We may notice several students frustrated after their initial attempts resulted in bulbs that did not light. Furthermore, we can't seem to find her desk; it appears to be in the back of the room, although it is hard to tell which is the back and which is the front of this classroom. Everything seems to be centered around the students.

Using the principles of cooperative learning and constructivist learning theory, Ms. Blake has carefully built a learning community in which inquiry and problem solving, along with careful attention to the ways of teacher-student and student-student interaction, are subtly arranged to promote deep and enduring learning. Ms. Blake approaches teaching and learning from a constructivist perspective and believes that we (both children and adults) construct our own understandings of the world. Therefore, the learning process must challenge us to reflect upon our interactions with objects and ideas and make sense of our world by synthesizing new experiences into what we already know or understand (Brooks & Brooks, 1993). Furthermore, Ms. Blake knows how important it is to challenge and empower students to "ask their own questions and seek their own answers ... to understand the world's complexities" (Brooks & Brooks, 1993, p. 5). Additionally, Ms. Blake realizes that to empower students to inquire and explore their worlds they must interact with one another as a community of learners and they must be able to do so frequently and easily. Ms. Blake also understands that for learning to occur students must struggle to understand their environment and that for true growth to occur students must learn to endure a period of mental discomfort or cognitive dissonance. Thus, she must design the physical and social structure of her classroom to enable students to work together cooperatively, embrace uncertainty and learn to enjoy the struggle to make sense of their environment.

Establishing a Cooperative Learning Classroom Environment

Ms. Blake values the use of cooperative learning tasks and understands the importance of creating a supportive physical and social classroom environment that will promote inquiry and problem solving among students. She wants students to make sense of their worlds and new information, and she knows students need to take risks in trying out new ideas and in explaining why something works or doesn't work. She understands that students accustomed to being told answers and how to proceed may experience frustration as they are forced to dig deeper and construct their own rules and explanations. She also recognizes that students benefit from being able to "think aloud" together as they struggle to understand and solve problems. Therefore, she organizes her lesson for small group, face-to -face cooperative learning. This choice for student grouping and goal structure is supported by research that consistently reports the benefits of cooperative goal structures (higher achievement and performance for a variety of educational objectives, efficient use of resources, and enhanced student self-esteem (Johnson, Johnson, & Smith, 1991; Johnson & Johnson, 1994). It is also entirely consistent with a constructivist emphasis on the social nature of learning and the essential role of dialogue in learning.

Ms. Blake's classroom projects and assignments require that they work interdependently so that they produce one outcome (a paper, a completed project, one set of answers, etc.). Furthermore, she knows that the success of the groups depends on the sum of each individuals contributions, group social skills and dependability. Thus she provides direct instruction in interpersonal and small-group skills so students understand that they are to promote productive working relationships (valuing and receiving input from all members) as they cooperate to complete a task. Students also understand that the groups are to work cooperatively, and if one group finishes their project before other groups, that they are to help other groups (Johnson, Johnson, Hollubec, & Roy (1984). Finally, students understand that they are each accountable to other members in their group as well as to each of their classmates and that their dependability as a group member and contributions to their group project will be assessed and evaluated. Ms. Blake creates the environment that Brooks and Brooks (1993) delineate as essential for constructivist classrooms:

> ... when the classroom environment in which students spend so much of their day is organized so that student-to-student interaction is encouraged, cooperation is valued, assignments and materials are interdisciplinary, and students' freedom to chase their own ideas is abundant, students are more likely to take risks and approach assignments with a willingness to accept challenges to their current understandings. Such teacher role models and environmental conditions honor students as emerging thinkers (p. 10).

Ms. Blake focuses on establishing a physical and social environment in which her students can become "emerging thinkers." Ideally, in such a learning environment, her students will want to take risks, explore new ideas and become deeply engaged in the process of inquiry and problem solving. To support her students' cognitive quest, she will need to focus considerable attention on understanding her students' constructions of what they encounter. For it is only through careful observation, listening and subtle questioning that Ms. Blake can understand their constructions (how they view the objects and ideas they encounter), and then determine how best to subtly intervene in the learning process. Excellent teaching has been described as having "transformative power" (Sprague, 1993), for teaching not only enlightens but also can empower students to learn. Sprague captures the dynamic of inductively oriented, interactive teaching by saying it "... works when students are fully engaged in the activities of the class ... when students persist and take risks ... when students become engaged with each other ... and become deeply engaged in the subject matter" (pp. 252–254).

Creating the Conditions to Guide Students' Learning: The Constructivist Lesson and Its Rationale

Some time after Ms. Blake is confident her students are acclimated to working effectively in cooperative learning groups, she decides to introduce them to the difference between a parallel and series circuit. Knowing that she must approach this lesson by "posing problems of emerging relevance to students" and by" structuring learning around primary concepts" (p. 35 and p. 46, Brooks & Brooks, 1993), Ms. Blake contemplates ways she can introduce the concept and need for understanding types of circuits to her students. She knows that students must have ample experience manipulating simple circuits before they can move on to the more complex parallel and series circuits. She decides to challenge her students to construct a simple circuit to discover the value of communicating and predicting what will and will not work so they will have a foundation for understanding the more complex parallel and series circuits. Thus, students will be asked to struggle with the concept of the flow of electricity and through trial and error, develop an understanding of the difference between parallel and series circuits. It is also abundantly evident that Ms. Blake has a detailed conception of her desired learning outcomes for her students and has prepared a carefully planned set of experiences to guide students to accomplish her goals.

Ms. Blake decides to begin the lesson by having students first complete a simple circuit using a battery, bulb and wire. As the students arrive for class and assemble in their groups, they discover the materials they need in a box for each group of two students. Ms. Blake knows that before students can move on to more complex circuits, they must first understand and be able to construct a simple circuit consisting of a battery, bulb and wire. She knows that many of her students do not understand that electricity must flow from the battery through the light bulb and back to the battery to make a complete circuit. She challenges them by asking, "Can you find a way to light the bulb using only one piece of wire and a battery?" Working in their groups, students eagerly attack the task. After an initial attempt to hook up the battery and bulb the students may report that they need two wires to complete the circuit. Ms. Blake assures them that it is possible to make the bulb light using only one wire and a battery. When Ms. Blake observes a group successfully lighting the bulb, she asks them to draw a picture of the circuit they have constructed and then to explain what they did and why they think it worked. She then challenges the group to see if they can find another way to make the light bulb light using only the materials they have. At this time it may be important to encourage the students by telling that there are as many as 5 or 6 configurations that will work. Each time a group successfully completes another configuration she challenges them with, "Can you find another way to make the bulb light?" Before moving on the more complex circuits, Ms. Blake may use whole group instruction to check for understanding by asking the entire class to respond to overhead drawings of circuits and predict which will light and which will not. When there is disagreement about a given circuit she simply advises the class to construct the circuit in question to see if it works.

After each group has successfully demonstrated its ability to construct a simple circuit, Ms. Blake challenges students with ever increasing degrees of difficulty such as making two or three bulbs light. Each group is challenged to generate rules for the circuits. Then she asks them to compare and contrast their various circuits and to discuss the advantages and disadvantages of each. She further challenges students to consider the aspects of the larger world by asking, "What circuit would work best for a flashlight, a Christmas tree, or a reading lamp? Why? Why do you think the flashlights are designed as they are?"

Once Ms. Blake is confident students understand simple circuits she challenges them to design a circuit that when one bulb burns out the other remains on (a parallel circuit). She illustrates the importance of this type of circuit by removing one of the light bulbs from the ceiling of the classroom as the students note that the other light bulbs stay on. This time she asks them to draw their proposed circuit first and then build the circuit to test their design. As she moves from group to groups she listens to the kinds of questions students ask each other as they struggle to adapt what they learned about simple circuits to a new problem. As students consider what might work, they reveal their "suppositions" about what they understand about circuits. Ms. Blake, in turn, carefully considers how to adapt her instruction on electricity to address any student misconceptions that have been exposed. As students compare and contrast their results and discuss reasons why knowing about circuits might be useful, they ask if they could examine a set of Christmas tree lights to see what type of circuit they contain. The successful performance of her pupils with parallel and series circuits informs Ms. Blake that they are ready to tackle even more complex circuit designs that may include buzzers and switches.

Since she is now certain that her students can identify and construct a parallel and series circuit, Ms. Blake now introduces them to electrical schematics she knows will pique their interest. These circuits may include the wiring plan for the school or the schematics for video games or audio devices. Next, in cooperative groups she challenges her students to prepare a list of the ways series circuits differ from parallel circuits. From these lists and the class discussion that ensues, her students come to realize the difference between parallel and series circuits. Next, she asks students to prepare a list of rules to remember when making a parallel circuit. Then students discuss the rules generated by the groups while Ms. Blake "mediates the environment" (p. 17, Brooks & Brooks, 1993) and provides any important rules that were missed by the groups. Finally, Ms. Blake asks each group to prepare either a complicated series or parallel circuit. Students then move from table to table to determine which type of circuit each group has constructed.

As her students begin their identification task, Ms. Blake moves from group to group so she can listen to discussions, observe students working on their projects, and intervene in the learning process, as she deems appropriate. Furthermore, as she observes, listens and interacts with students, she evaluates their understanding; this information about her students' present understanding will guide decisions about future lessons.

In this constructivist lesson Ms. Blake has created a classroom environment rich in student-to-student interaction formed around challenging problem-solving projects relevant for her students. Learning in her classroom occurs when students struggle to make connections from what they know in relation to the more complex and larger world. Ms. Blake has set in motion a fertile environment in which to stimulate her students' growth as emerging thinkers who trust and value their own and each others' questions and answers. Not until the students developed an understanding of the difference between the two types of circuits did Ms. Blake identify these circuits as parallel and series. This constructivist vision of a teaching emphasizes that teachers "... look not for what students can repeat, but for what they can generate, demonstrate, and exhibit" (p. 16, Brooks & Brooks, 1993). As Kaufman (1996) states, "Learning does not occur in a vacuum and is best mediated through supportive social networks" (p. 44).

Myths About Constructivism

There are certain misconceptions and myths that have evolved concerning constructivist instructional practices. They stem primarily from misinterpretations of underlying principles of learning posited by constructivism. In this section, misconceptions and myths will be identified, analyzed and countered.

Constructivism posits that learners construct their own reality based upon their individual perceptions of prior experiences. Thus, each person's knowledge is a function of his or her prior experiences, how they are perceived and how they are organized. Once organized into complex mental structures, we use our cognitive frameworks to interpret objects, ideas, relationships, or phenomena (Brooks & Brooks, 1993, Jonassen, 1993: Jonassen, Peck, & Wilson, 1999). Thus, what a person knows is grounded in one's unique perception of his or her physical and social experiences; and we use our varied mental capabilities to explain, predict, or make inferences about phenomena in the real world (Jonassen, 1991).

These assumptions about how learners learn give rise, in turn, to important practical questions about constructivism applied to teaching. Specifically, if learners must each construct a unique reality, one that resides in the mind of the learner, then:

a) How can teachers create a purposeful/focused learning environment?
b) How can teachers determine and ensure a common set of learning outcomes for students?
c) How can teachers plan a set of instructional events or conditions when there is such unpredictability about what learning will be acquired?

Erroneous answers to these questions based on fundamental misconceptions have resulted in at least five detrimental myths about constructivist instruction. Each will be clarified in the discussion below.

Myth 1: There is no focus for learning, no clear goal in constructivist-based instruction.

Is it possible to create a purposeful learning environment under the knowledge construction assumptions of constructivist learning? The answer is an unqualified yes. Constructivism maintains that learning is purposeful, intentional and collaborative (Scardamalia & Bereiter, 1994), and that learners will actively strive to achieve a cognitive objective. However, constructivism does not prescribe a particular set of activities and thought processes in which the learner must engage in order to achieve intended learning. Nor does it offer clear guidelines for establishing a particular sequence of instruction. By no means does this imply that no learning outcomes are identified for learners as a group or that instruction cannot be planned in any systematic way (see Ms. Blake's case for a concrete example). Rather, it emphasizes the design of learning environments that focus on knowledge construction, instead of reproduction (Duffy & Jonassen, 1993). Such environments, as Jonassen (1991) puts it, "are not unregulated, anarchic, sink-or-swim, open-discovery learning cesspools that many fear" (p. 136). As illustrated in Ms. Blake's case, constructivist learning environments are carefully designed for a knowledge construction task. Designing such a constructivist learning environment is admittedly a difficult task because there is a certain degree of unpredictability of outcome and complexity in knowledge construction process.

Myth 2: Constructivist based instruction is not thoughtfully planned; careful preparation is less important than in traditional instruction.

From Ms. Blake's example we learn that to design a constructivist learning environment, a teacher must first define a learning focus, some challenge, case or problem. What constitutes a problem is any relatively complex task (for the given learner), and ideally, one that is an authentic activity (i.e., design and construct a parallel and a series circuit). She also has to define a set of instructional goals and objectives, that is, specify what the learner must know to meet the task/challenge (how to construct a simple circuit, how to design and construct a parallel and a series circuit, identify the differences between a parallel and a series circuit). The learning strategies (where and how the learner will obtain those skills and knowledge) and the tools that can be used to better understand the problem/task/case must be identified as well. However, all of these design decisions are negotiated and refined through a collaborative process between the teacher and learners (see Ms. Blake's case).

Once students are presented with a learning focus or challenge, the teacher and learners negotiate and refine what the learners have to learn (based on individual prior learning histories and predilections), where and how they are to acquire the knowledge and skills, and how they are to demonstrate the intended learning (performance criteria). Among the more important aspects of the teacher-student negotiation is reaching agreement on how the learner will demonstrate the desired learning performance. Without question, then, there is concern for validating the quality of students' achievement (i.e., assessing students' learning).

For example, the teacher in Moll and Whitmore's study (1993) explains how learners in her class participate in designing the constructivist learning environment and the degree of control that the learners have over their knowledge construction process.

> "The theme cycles are pretty much controlled, the topics anyway, by the kids. Right away at the beginning of the year we go through a group brainstorm process where the kids will put out anything they are interested in studying, and we put sharks and whales in the list together with some [who] said ocean, so that related topics are chunked together. And then the kids are asked to vote for their ten most favorite, and those are the ones that we do as group theme cycles for the year. I put my things on the list too" (p. 30).

Continuing, she explains how she designs each lesson and collects proper materials, saying:

> "[It] usually starts with some kind of web, sometimes the kids would share what they already know. I usually ask them to generate lists of questions of what they want to know about and that helps arrange centers or activities, knowing what they're interested in, what their areas are" (p. 30).

As the above example and Ms. Blake's case show, in a constructivist learning environment, clear educational goals are established, authentic tasks and real-world, case-based experiences and contexts (rather than pre-determined instructional sequences) are carefully designed and sufficient verbal interaction between the teacher and students and among students is ensured.

Myth 3: There is an absence of structure for learning in a constructivist learning environment.

As illustrated in Ms. Blake's case, structure also exists in a constructivist learning environment. It emerges in two ways. On the one hand, a curriculum or a lesson has an organizing topic, task or question (design and construct a parallel and a series circuit) that sets the initial direction of the classroom conversation (Applebee, 1996). This overall focus provides direction for decisions for creating a seminal learning experience and key essential learning materials, as well as what will be peripheral to the principal topic or task. The judgment of which potentially related topics will be relevant to the learning of the broader instructional goal, however, will continue to evolve in response to the interests and knowledge of each group of students (see Ms. Blake's case).

The second aspect of structure involves the relationships among the various parts of a learning experience. For example, when presented with a problem to be solved, the teacher and learners search for its causes, note similarities and differences with tasks with which the learners are familiar, and classify it hierarchically or taxonomically as part of a larger system. Thus a constructivist teacher engages in a complex planning process although one that is different from what is prescribed in typical instructional theories.

Myth 4: As long as learners are involved in discussion and other forms of social interaction, learning will take place.

As demonstrated in Ms. Blake's case, in a constructivist learning environment, teachers must monitor discussions carefully to see if students get off track or develop misunderstandings about the topic, or if there is a need to intervene and redirect the discussion (Brown & Campione, 1994). It is imperative that the teacher carefully monitor group work and whole-class discussion and intervene as necessary to keep students on track, to stimulate consideration of key issues and perspectives, and to lead students to correct their misunderstandings. This calls for highly sophisticated teaching, requiring careful teacher judgment, essential aspects of the constructivist teacher's role.

Myth 5: Since teachers are not primarily engaged in delivering instruction (lecturing and explaining), their role in the classroom is less important.

In a constructivist learning environment, the teacher is certainly no less important; but the role of the teacher changes so that the focus is on guiding rather than telling the learner. Indeed, an argument can be made that teachers' roles are both more important and more difficult when teaching based on constuctivist views of learning. Guiding students to genuine understanding is a sophisticated process; no rules tell us when to intervene or how extensive the intervention should be. Teachers must make these decisions on their own, based on their knowledge of subject matter, learners, and learners' past experiences. Moreover, the number of on-the-spot decisions that teachers must make in a constructivist learning environment requires skillful, reflective and spontaneous teachers who are capable of mentoring, coaching and facilitating students' learning.

Enduring Issues in Constructivist Pedagogy

In addition to the above-mentioned myths, there are some important educational issues that need to be raised with respect to the structure and duration of learning tasks and the nature and efficacy of learning challenges posed to learners. We next explore three such issues.

Issue 1: Degree of Structure in Learning Tasks

Very often new teachers preparing to enter the profession or in-service teachers engaged in school change efforts ask the same question about their ability to transform constructivist learning theory into classroom practice. They ask: How could I possibly maintain a structured learning environment if students spend so much time designing their own investigations and I spend so much time mediating those various investigations? How could I keep everyone focused, on-task and learning with so little structure.

The structure in the constructivist classroom may look different than what some teachers originally envision when they think of the term, but it is there nonetheless. Structure in the constructivist classroom is negotiated with the child and can include norms, procedures and policies that could easily go unnoticed by the novice eye. In one setting, students might move about the classroom freely to get supplies, meet study group members, confer with the teacher or return to work started at an earlier point. And students' have the opportunity to be self-directive or not as they desire.

The constructivist teacher incorporates lessons of all types into classroom life depending upon her analysis of the needs of her learners. One day a visitor might find this teacher encouraging students to share their interpretations of characters in the book they are each reading. Or, they might find this teacher leading a session in which she is sharing the conventional forms of a business letter to a group of student with rough drafts. In these cases, the structure (small group meetings with the teacher) may look similar, but the teachers' instructional objectives and students' opportunities to change their current perspectives are different.

In another constructivist classroom, the students may be seated in rows facing the chalkboard working on an arithmetic problem. Let's examine a particular problem and the teacher's role in guiding students to solving it. The teacher has presented an ill-defined problem involving how to configure the tables for that evening's parent open house with the constraint that the tables seat a maximum of 6 and there are 87 parents attending that evening. The students are trying to determine how many tables they need to set up for the open house. The teacher encourages multiple interpretations of the problem and multiple pathway solutions. Of particular interest to the teacher is how the students deal with the remainder, since six is not a factor of 87. The students' differential responses will help her determine which students' understandings of the part/whole relationship will make instruction with more sophisticated division problems appropriate and which students can benefit more from further problems with the part/whole/remainder relationships.

The above classroom illustrations serve to describe the variability of classroom structure compatible with constructivist pedagogy. Constructivist learning theory is not prescriptive, neither dictating classroom structure nor teaching technique. It does explicitly state that conceptual change is the key to cognitive growth and development, and thus conceptual change becomes an essential quest for the teacher's professional action. The precise nature of that endeavor is derived form the teacher's negotiations with the learners.

Issue 2: Efficiency of Learning

Because teachers have limited instructional time, the manner in which time is used in the classroom will always be a concern for teachers. Teachers feel considerable pressure to complete the requirements of their assigned curriculum. Thus it is predictable that teachers and educators in general will raise questions about how to accomplish the most with the time that is allocated. However, answers to questions of efficiency are not easily answered. There is neither universal agreement concerning precisely what the outcomes of schooling should be, nor agreement about what methods yield efficient and lasting learning. And if one's goal is to enhance the transfer of learning, the answers become even more varied.

Constructivists value asking big questions, giving students time to think, and providing opportunities to explore to find answers. While this way of teaching requires more time, by ensuring sufficient time, students gain a better grasp of complex ideas. Moreover, deliberate investigation by students tends to foster the disposition to pursue issues and phenomena more completely, even those that are more difficult. Many lament the fact that school curricula contain so much material that it is almost impossible to cover it all. But where is the learning in "coverage?" When the emphasis in school is placed too heavily on information and its recall, the inevitable result will be prodigious amounts of forgetting. Thus, the position of constructivist educators is not to worship efficiency, but instead to value the quality of the learning. They subscribe to the principle that "more is less." On the surface it may appear that efficiency is sacrificed, but the more important outcome for learners of all ages, it is argued, involves learning with depth.

This is certainly not to say that teachers should be unconcerned about how they manage their instructional time, for nothing could be further from the truth. One may badly squander precious learning time through the poor application of any instructional methodology. Therefore, it is of utmost importance for effective constructivist teaching that the conditions for learning be carefully structured, and that students' learning activities and learning be carefully monitored. Competent constructivist teaching demands not only full engagement by students, but also meaningful engagement and accountability by teachers. Where tension arises over efficiency of instruction, constructivists will accentuate the goal of achieving depth of learning rather than breath of learning (Brooks & Brooks, 1993). In the final analysis, what is of enduring significance is that learners acquire deeper levels of understanding, see their learning in a meaningful context, become increasingly competent (and yes, efficient) learners, and have the awareness and ability to apply their learning in non-school contexts.

Issue 3: Efficacy of Learner "Struggle" in the Process of Learning

Constructivists believe that meaningful learning or "purposeful knowledge" may be promoted by a learning environment that has three main features. First, one should use authentic problems, that is, tasks having the contextual feel of the real world. Secondly, the learning environment should represent the natural complexity of the real world and avoid oversimplification of the task and instruction. And thirdly, a constructivist learning environment should support collaborative knowledge construction through social negotiation (Jonassen, 1991). It is believed that such learning environments invite learners through interaction with others to engage in problem finding, problem solving and inquiry learning. Through the combination of complex, real-world problems and meaningful social interaction among learners and teacher, constructivists assert that learners are encouraged to discover or invent new rules or revise old rules and in the process come to a deeper understanding of underlying concepts and principles. The discovery process embedded in a constructivist learning environment also allows learners to reevaluate what they know, and to change their understanding based on what they have directly learned from their environment. Constructivists argue that the open-ended, problem-based, inquiry learning characteristics of constructivist learning environments require learners to struggle with the ill-structured, real-world problems in order to solve them.

One of the fundamental underlying principles of constructivism is the concept of "sociocognitive conflict." This mechanism for learning, derived from the work of Piaget and his disciples, proposes that cognitive conflicts lead to higher levels of reasoning and learning (Webb & Palinscar, 1996). Cognitive conflict arises through the dynamics of social exchange when the learner realizes that there is a contradiction between his/her existing understanding and what he/she is experiencing. Constructivists claim that it is reasonable to believe that the best environment for creating such conflict is an environment in which problems are posed, questions are raised and alternative perspectives are presented. Problem-based environments also promote peer collaboration and exchange of ideas, which are the major sources of cognitive conflict (Piaget, 1976). Evidence shows that giving up one's current understanding in order to reach a new perspective will be best attained by an exchange of ideas (Damon, 1984; Radziszewska & Rogoff, 1991).

From a motivational perspective, evidence shows that since problem-based, inquiry learning environments simulate real world situations, students' natural curiosity is stimulated and learners find their learning experiences to be more interesting, more engaging and more relevant. Furthermore, problem-based environments make higher cognitive, metacognitive, affective, and resource management demands upon the learner. These high level demands encourage learners to develop expertise in how to learn as well as in learning to construct useful knowledge (Perkins, 1991). A problem-based learning environment is much more likely to engage learners in the learning process through identification, formulation and restructuring of goals; planning; development and execution of plans; self-monitoring; and appropriate use of resource management strategies.

Summary and Recommendations

While more research is certainly needed on constructivist methods of teaching, there is growing evidence of the efficacy of well-implemented programs (Bereiter & Scardamalia, 1987; Carpenter & Fennema, 1992; Duffy & Roehler, 1986; Neal, Smith, & Johnson, 1990). In their Cognitively Guided Instruction (CGI) mathematics program (Carpenter & Fennema, 1992), elementary school teachers are given extensive training in constructivist methods (complex problems, modeling, group problem solving, careful teacher questioning and teaching of metacognitive strategies) and have found increases in higher-level thinking skills as well as solid achievement in traditional computational skills. Constructivist approaches to mathematics emphasize the use of real problems for students to solve intuitively (Fuson, 1992; Lampert, 1986). Once students have achieved a sound conceptual understanding, they are then taught the formal abstract representations of the discovered mathematical processes.

Constructivism has been widely embraced by science teachers as well as teachers of mathematics. Since constructivist epistemology is entirely consistent with an inquiry approach, we see its principles manifested through investigative laboratory activities, cooperative learning and a variety of hands-on experiments combined with expert scaffolding. In addition to positive outcomes in science (Neale, Smith, & Johnson, 1990), similar successes have been reported in reading (Duffy & Roehler, 1986) and in writing (Bereiter & Scardamalia, 1987), as emergent literacy practices have become adopted increasingly in language arts instruction. However, much of the research continues to be descriptive rather than comparative, and the intended outcomes of constructivist instruction are often qualitatively different from traditional methodology. However, Airasian and Walsh (1996) do caution that the representation of constructivist views of knowledge and learning in teaching pedagogy has not been sufficiently explicated.

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under what conditions will specific constructivist approaches be most effective for enhancing student achievement? For which learners and for what learning outcomes will constructivist methodologies be most efficacious? More research is needed to answer these questions. And they also point out that students do construct meaning in a variety of ways.

Although constructivism is a theory about learning rather than a description of teaching, some important strides toward defining the relationship between theory and practice have been made. The following pedagogical recommendations, while general in nature, have been derived from fundamental constructivist principles of learning (Confrey, 1990; Brooks & Brooks, 1993; Fosnot, 1996).

1. Learners should be encouraged to raise questions, generate hypotheses and test their validity.
2. Learners should be challenged by ideas and experiences that generate inner cognitive conflict or disequilibrium. Students' errors should be viewed positively as opportunities for learners and teachers to explore conceptual understanding.
3. Students should be given time to engage in reflection through journal writing, drawing, modeling and discussion. Learning occurs through reflective abstraction.
4. The learning environment should provide ample opportunities for dialogue and the classroom should be seen as a "community of discourse engaged in activity, reflection, and conversation" (Fosnot, 1989).
5. In a community of learners, it is the students themselves who must communicate their ideas to others, defend and justify them.
6. Students should work with big ideas, central organizing principles that have the power to generalize across experiences and disciplines.

To this set of recommendations we would add the following concluding thoughts. The overriding goal of the constructivist educator is to stimulate thinking in learners that results in meaningful learning, deeper understanding and transfer of learning to real world contexts. To accomplish this goal, a constructivist framework leads teachers to incorporate strategies that encourage knowledge construction through primarily social learning processes, in which students develop their own understanding through interactions with peers and the teacher. In addition, in order to make manifest and link new knowledge to learners' current understanding, the constructivist teacher selects authentic tasks and uses more ill-defined problems and higher order questions. A significant problem tackled by small groups of students promotes involvement, curiosity, and heightened motivation.

Thus, it is desirable that constructivist lessons have a clear content goal designed around an authentic learning task, question or problem. The teacher must also select multiple ways of representing key ideas in the lesson, thereby providing students multiple ways of connecting, integrating and elaborating the new learning. By arranging for student interactions in conjunction with highly skilled, teacher questioning, teachers can promote students' thinking skills, guide students' learning, and assess students' learning as they learn. Students in constructivist classrooms are challenged to become more active learners, to interact with their peers and to always view learning as a search for meaning. At the same time, the teacher is challenged to know her learners, to observe and listen to their responses and thinking. The teacher must model effective thinking employ expert questioning, and otherwise, skillfully provide whatever learning guidance may be indicated to support the efforts of students to construct meaning from their classroom and life experiences. By following these guidelines, teachers and students will experience greater efficacy, as students take increasing responsibility for their learning and come to appreciate the satisfaction of meaningful learning.

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Collaborative Concept Mapping: Provoking and Supporting Meaningful Discourse

An important aim of instruction in schools is that students learn the concepts that are used within specific domains, and that they improve their ability to use these concepts in their mutually agreed-upon "scientific" meanings. Several authors suggest that students learn domain-specific concepts by using them in spoken communication—through talking about and "with" concepts (Duit & Treagust 1998; Lemke, 1990; Palincsar, Anderson, & David, 1993). From this point of view, then, collaborative learning tasks have a strong potential to contribute to the learning of concepts, because they can provide students with the opportunity to talk about and use them to describe and explain phenomena. In addition to the composition of the group, the group size, the reward structure, and the preparation for group work, the task itself has an important role in shaping the quality of the student interaction (Derry, 1999; Van der Linden, Erkens, Schmidt, & Renshaw, 2000; Webb & Palincsar, 1996).

In this article we discuss the potential of collaborative concept-mapping tasks. In our research, we used a concept-mapping task in three experimental studies. Participants in the studies were 15- to 16-year-old students from secondary-level physics classes. The students collaborated in pairs on a concept-mapping task that functioned as the introduction to a new course about electricity. In each study, we manipulated the task design and compared the student interaction that emerged in the different task conditions. In all studies, we videotaped and transcribed the student interactions and analyzed the transcripts.

Several studies (Horton, McConny, Gallo, Woods, & Hamelin, 1993) have shown that concept mapping results in meaningful learning. Making a concept map helps learners become aware of and reflect on their own (mis)understandings; it helps students take charge of their own meaning-making. Further, it contributes to the development of an integrated conceptual framework. Most of the concept-mapping studies focus on the construction of a concept map by individual students or a teacher. In line with the findings of Roth and Roychoudhury (1993, 1994) and Sizmur and Osborne (1997), we concluded that concept mapping, as a collaborative learning activity, is successful in provoking and supporting a student discourse that contributes to the appropriation of physics concepts. Students in the three studies in which we used concept mapping as a group task showed significant learning gains (van Boxtel, 2000). It appeared that the learning outcomes were related to the quality of the student interaction. The more talk about physics concepts and the more elaborative that talk, the higher the learning outcomes.

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In the following sections, we present our experiences with the concept-mapping tasks used in our research. We identify the features of the concept-mapping task that helped make it successful in provoking and supporting a productive student discourse.

Collaborative Concept Mapping

The concept-mapping task

Concept maps are diagrams indicating interrelationships among concepts and representing conceptual frameworks within a specific domain of knowledge (Novak, 1990). A concept map represents the main concepts and relationships within a domain. It is a network in which the nodes represent concepts, the lines linking the nodes represent relationships, and the labels on the lines represent the nature of the relationships. Within the domain of physics, the relationships between concepts mostly reflect physical regularities. For example, within the domain of electricity, the concepts of voltage, current strength, and resistance can be related to each other. It is possible to describe the relationships among these concepts as follows: "If the voltage increases, then the current strength increases, provided that the resistance does not change." This is a qualitative description of Ohm's law ($I = V/R$) that accounts for the observation that current strength is proportional to the amount of voltage.

In our studies, pairs of students were asked to construct a concept map on a large sheet of paper, and use a given set of electricity concepts, such as current strength, voltage, energy, and resistance. We expected students to connect related concepts and label the links that represent the relationships between concepts precisely. We chose to work with students from the higher grades because a fruitful discussion about the meaning and use of concepts requires that the participants are at least familiar with the terms and have some initial understanding of the concepts and their interrelationships. It took students an average of 20 minutes to construct a concept map like the one shown in Figure 1.

In the following sections we give a description of the student discourse that was provoked by the concept-mapping task (see van Boxtel, van der Linden, & Kanselaar, 2000 for more details of the study). We will relate the features of the student discourse to the features of the concept-mapping task.

Students articulate their thoughts

As expected, collaborative concept mapping engaged students in discourse about the physics concepts. The students articulated their thoughts about, and experiences with, the concepts. There was almost no off-task talk. The requested group product and the given electricity concepts forced students to pay attention to key principles in the

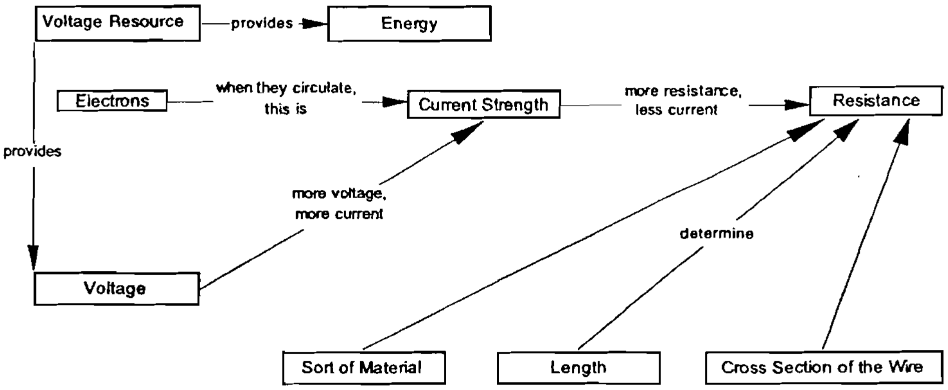

Figure 1. Example of a concept map about electricity.

domain, thus stimulating "abstract talk." The average intensity of talk about the electricity concepts was measured as the number of propositions per minute. We defined a proposition as an utterance in which the student makes a statement about the meaning of or a relationship between one or more electricity concepts. The students formulated approximately three propositions per minute. In almost all pairs, the students participated equally in the discourse.

Most conversation about the electricity concepts concerned relationships among concepts. Usually, the formulation of relationships became more precise and specific during the accomplishment of the task. "Resistance and current strength are related" is an example of a proposition with low specification. "If resistance is small, the current strength is large" is an example of a proposition with high specification.

As a result of explaining their own conceptions, students gain a greater conceptual clarity for themselves (Damon & Phelps, 1989). However, Roth and Roychoudhury (1993) reported that some negative outcomes could occur. For example, as a result of working together, students' scientifically incorrect notions sometimes become ingrained or go unchallenged. When a concept-mapping task is used as the introduction to a curriculum unit, however, this could be considered less of a problem and, perhaps, even meaningful. The subsequent student activities and instruction can be focused on an explicit comparison of new information with the conceptions that are expressed in the concept maps. Becoming aware of one's own conceptions, knowledge gaps, and inconsistent reasoning can be considered important conditions for conceptual change, because it may result in a cognitive conflict (Joshua & Dupin, 1987; Pintrich, Marx, & Boyle, 1993).

Articulation of ideas also enables students to question or criticize them. A partner can point to inconsistent or incorrect reasoning and elaborate ideas, and both students can co-construct meanings. In the next sections, we discuss the potential of the concept-mapping task to provoke elaboration and co-construction.

Elaboration of conceptual knowledge

Learning concepts requires deep processing activities, such as the active use of prior knowledge, the recognition and acknowledgment of problems, and attempts to look for meaningful relationships. Because a concept-mapping task is an open task with no predetermined or fixed answers, collaborative concept mapping elicits negotiation. Negotiation processes can be characterized by asking and answering questions, resolving disagreements, and co-constructing meanings. Questions asked during the concept-mapping task (i.e., "What is voltage?" "Why is a voltage resource needed in an electric circuit?" "But what actually is a molecule?") included the acquisition of the theoretical framework of electricity concepts as used by scientists. The fact that the questions were posed by the students themselves seemed to make them eager to search for an answer. In attempting to answer the questions, students can create new relationships by giving examples, using analogies, reformulating, or by referring to school or everyday experiences (see also Webb, 1989, 1991).

The concept-mapping task also provoked conflicts, because in talking about relationships between certain physical quantities, students often had to choose between two opposite alternatives. For example, current strength is either directly or inversely proportional to resistance; voltage is related to electrons, or it is not. A concept map requires an explicit answer. This might explain why, in our studies, students elaborated almost all conflicts that arose. One student explained or justified his or her statement, or both students contributed to the resolution of the conflict through argumentation about the solution.

Co-construction of meanings

When peers work on a common task, mutual understanding must be created and sustained continuously (Roschelle, 1992). To coordinate activities and achieve a joint concept map, the collaborating students needed to create a shared meaning of the task, the concepts, the procedures, and the strategies to use. The transcripts of the student discourse showed many episodes in which *both* students contributed to answering a question, resolving a conflict, or constructing a reason.

The following example illustrates the process of co-constructing a reason. After Haiko states that an electric circuit has a voltage source, he (finishing the proposition that Andy started) states that a voltage source gives voltage. Then, Andy continues to relate the voltage source to energy and to current strength. Finally, Haiko relates the concept of current to the concept of energy.

> Haiko: An electric circuit has a voltage source too, hasn't it?
>
> Andy: Yes, actually it has.
>
> Andy: (draws)
>
> Andy: And it consists of (writes) . . . And the voltage source has . . . gives, gives . . .
>
> Haiko: The voltage source gives voltage . . .
>
> Andy: and energy.
>
> Haiko: Yes also . . .
>
> Andy: and current, isn't it? The voltage source also gives current.
>
> Haiko: And due to this current, there is energy.

We suggest that such collaborative episodes contribute to the learning of concepts, because both students are actively engaged in elaborative activities at the same time. They are not only reflecting on and elaborating their own understanding but are also integrating and elaborating the input of their partners.

Next to the use of language, shared objects and tools can also play an important role in the negotiation and co-construction of meanings during communication. Crook (1998) argues that collaborating students will benefit from referential anchors because they can support the construction of a shared understanding: "The more abstract the terms of the problem, the more helpful it may prove to have external representations that resource the construction of a shared understanding" (pp. 241). During collaborative concept mapping, the product serves as a visible representation that can facilitate communication about abstract concepts and relationships. Students can refer to the concept labels and the propositions of the emerging concept map while verbalizing their ideas and negotiating meaning. In addition, the use of a large sheet of paper makes it difficult for students to divide the task into parts, and strengthens interdependency and negotiation between the collaborating students.

In sum, the collaborative concept-mapping task prompts students to articulate their thoughts, elaborate the meaning of the physics concepts, and co-construct conceptual understanding. However, there are also some limitations. In the next section we discuss these limitations and the strategies that can be used to overcome them.

Limitations and Strategies

Limitations of creating a concept map

The results of our analyses with the concept-mapping task in a number of studies show that collaborative concept mapping has a strong potential to elicit elaborative talk about the relationships among the electricity concepts. However, at certain points the concept-mapping task was not as provocative as we'd hoped it would be.

First, a concept map does not elicit much discourse in which concepts and their interrelationships are used to describe and explain phenomena in concrete electric circuits. Most student discourse is about the theoretical relationships between concepts. Second, we discovered that the discourse rarely reached the explanatory level. For example, many students stated that higher voltage results in higher current strength, but most students did not talk about how this relationship could be explained. This may be due in part to a lack of experience with such dialogue. Most of the physics textbooks used in secondary education do not explain described regularities, and the assignments do not give much opportunity to practice the formulation or generation of explanations. To engage students in discourse about explanations, it may be necessary to request a group product that really requires discourse at this level. Third, although students can be asked to include quantities and formulas in their concept maps, this does not really provoke elaborative talk about other forms of representation.

Finally, the construction of a concept map elicited the articulation of only some of the conceptions that are considered frequently occurring misconceptions within the domain of electricity. For example, the student discourse during the construction of the concept map especially reflected the confusion between voltage and current strength, and the idea that a larger cross-section of a wire results in a larger resistance. One of the most frequent misconceptions within the domain of electricity is the idea of "current consumption" (e.g., Driver, Squires, Rushworth, & Wood-Robinson, 1994), yet this idea was articulated by only 1 of the 20 pairs of students that participated in the mapping task.

To overcome such problems, the concept-mapping task can be extended with a phase in which students are asked to elaborate relationships on their concept maps. In the following section we describe this extended concept-mapping task.

Elaborated concept mapping

In the restricted, commonly used concept-mapping task described previously, students constructed a concept map. This task can be extended in the following ways:

1. Ask students to design experiments that would prove the regularities they describe in their concept maps. Each experimental design has to be described in words and represented in a drawing (e.g., a drawing of an electric circuit with a resistor, a voltage source that can supply different amounts of voltage, and an ammeter to measure current strength).
2. Ask students to represent the expected results of the designed experiments in a diagram.
3. Ask students to give an explanation for the nature of the relationships in their concept maps and represented in the diagram.

We have examined these ways of elaborating the concept-mapping task in two additional studies. In these studies, students could use a poster that was already structured and provided parts for the experiment, the diagram, and the explanation.

Because we asked students to construct a concept map first, and then to elaborate the relationships in the concept map, we could compare the student discourse that occurred during the construction of the concept map with the student discourse that occurred during the elaboration of it. As expected, the design of experiments and the drawing of diagrams elicited more interactions in which students related the electricity concepts to concrete phenomena and other forms of representation. The design of experiments also provoked the sharing of previously completed experiments and demonstrations in physics classes and the articulation of the idea of current consumption. We describe our experiences with the elaboration of the concept map in more detail below.

Articulation of misconceptions

During the design of the experiments, students often expressed the idea that an electric circuit uses up current, and that an intervention in the circuit affects only the part behind the intervention. In the following example, Winnie and Christine decided to draw an electric circuit with a piece of wood, because they hypothesized in their concept map that certain materials have a high resistance and, therefore, can't conduct current. Winnie's statements reflect the idea of current consumption or local reasoning, because she assumes that there will be a current between the battery and the piece of wood, but not between the piece of wood and the bulb.

> Winnie: I think we have to measure current strength, but how can we do that?
>
> Christine: I think the piece of wood has to be between the battery and the bulb; otherwise, we can't determine whether it conducts. . . .
>
> Winnie: Here (points) . . . it's between the battery and the bulb.
>
> Christine: Then we must connect these ones, because it results in. . . .
>
> Winnie: Yes, but look, when the current is going like this, then it doesn't come back, does it? When this does not conduct, it can't come back again.

Discussing other forms of representation

The task of designing experiments elicited student discourse about the way an electric circuit must be built and how it can be drawn using circuit diagram symbols (for example, a bulb is a circle with a cross). Many students referred to experiments that they had carried out previously in the physics class. This occurred, for example, when they were discussing how the physical quantities could be measured. When students tried to represent the expected results of the designed experiment in a diagram, they discussed how the quantities had to be represented in units and symbols and which variable had to be put on which axis.

Discussing explanations

The transcripts of the student discourse showed that students had difficulties with the generation of explanations for the "if-then" relationships they described in their concept maps. Some students' suggestions (e.g., "Because it isn't otherwise." or "Some Einstein invented it.") presupposed that the relationships did not need further explanation. Such utterances may be related to the conception that physics contains well-defined and "finished" knowledge that does not need further explanation. Yet some pairs of students discussed the implications of giving an explanation (e.g., "Actually, this is a ***description*** of what happens, but what is the ***explanation?***" or "You have to know why; why does the resistance increase?").

Conclusions

In this article, we showed the importance of the quality of student interaction, and that the design of the task can affect that quality. The task must be designed primarily on the basis of the kind of student discourse that is thought to be productive. In the case of concept learning, productive student interaction is characterized by discourse about the meanings and relationships of the concepts, elaboration of conceptual knowledge, and co-construction of meanings. A concept map functions as a useful tool to provoke such student interaction.

Several features of a restricted concept-mapping task explain why productive student interaction occurs: the required group product (a) is large enough to be shared, (b) contains visually represented information, (c) does not require many concrete activities (e.g., drawing and writing) at the cost of abstract talk, and (d) forces students to actually use the scientific concepts and discuss their meanings and relationships.

The group task to elaborate the concept map provokes other types of valuable elaborative talk: (a) relating abstract concepts to concrete phenomena, (b) sharing the results of experiments and demonstrations from previous physics lessons, (c) relating concepts and relationships between concepts to symbolic and graphical forms of representation, and (d) discussing principles that underlie regularities. Including a step where students have to prove and explain the relationships in the concept map seems to be a good extension of the task because it stimulates students to talk about multiple kinds of relationships.

The concept-mapping task described in this article can be used in educational practice in several ways. While it may not be strong enough to change students' misconceptions, as an introductory task, concept mapping can encourage them to verbalize their conceptions, to discuss them, and to elicit the need to answer questions and test assumptions. A concept map is a good instrument for teachers to quickly diagnose students' use of misconceptions. The collaborative concept-mapping task can also assist students in taking more responsibility for their own learning during the course. Eventually, with the teacher's help, students can determine which activities to use to check or improve their concept maps—the hypotheses and explanations they formulated. Further, the concept map, designed experiments, and explanations can be presented and discussed in class. In this way, a concept map and the designed experiments can evoke students' discussion of what constitutes proof for a relationship, and what constitutes an explanation within the domain of physics.

In sum, a collaborative (elaborated) concept-mapping task enables students to use language for thinking and reasoning together (Mercer, 2000; van der Linden & Renshaw, in press). It is a powerful task because it stimulates and supports the articulation, elaboration, and co-construction of meaning and sense.

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