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Challenges and Promising Approaches in the Teaching and Learning of Introductory Physics at the Secondary Level

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Abstract

High school students arrive at an introductory course in physics with a number of naive beliefs constructed through daily interactions with the physical world. Although there is disagreement about the structure of these beliefs, most would agree that they are robust and that some form of strong conceptual change or restructuring is needed to adopt a Newtonian view. Physics teachers at the secondary level are charged with facilitating this strong conceptual change. Empirical studies from the field of Physics Education Research (PER) have demonstrated some success in this effort. Most studies have included a component of peer interaction as part of the instructional protocol. Yet, despite widespread dissemination of these research results, more "traditional" teacher-centered instructional approaches continue to be employed in many secondary settings.

The success of interactive methods in physics and other disciplines is supported by socio-constructivist theories of teaching and learning. Some see the role of the teacher as one of providing the 'scientific' concept, through formal instruction. Students use their 'spontaneous' or naive concepts to build understanding through their own active, cognitive work.

The purpose of this review is to identify the challenges facing secondary teachers of physics, to explore the most common instructional methods currently in use and to propose future research that will lean heavily on the use of peer collaboration to foster strong conceptual change. The review is organized in two

main parts. The first will focus on exploring the challenges facing teachers of introductory physics at the secondary level. It will examine the difficulties students face in developing an expert, Newtonian view and how these difficulties are most commonly addressed in the secondary classroom. Readings about teacher beliefs and pedagogical content knowledge will be included next, followed by a description of current curriculum and frameworks requirements and recommendations. The goal of this portion of the review will be to explore why, despite their apparently limited success, traditional methods might still be so prevalent.

The second part of the review will focus on some promising instructional models many of which employ some form of peer collaboration. These will include empirical studies from the field of Physics Education Research (PER) and other domains. The review will consider theoretical frameworks that may help to explain the success of such models and will consider some literature that examines the explicit mechanism through which peer-to-peer dialogues may support strong conceptual restructuring or change.

Through this review, I will argue that: (1) Strong conceptual change or restructuring is needed for high school students to develop as Newtonian thinkers; (2) Peer-to-peer verbal interactions may have an important role to play in this process; (3) Combined quantitative and qualitative studies, at the secondary level, are needed to contribute to our understanding of this process for students enrolled in introductory physics courses; and (4) Careful analysis of interaction transcripts will be necessary to inform our understanding of the mechanism involved in conceptual restructuring in this setting.

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> *"Transmitted knowledge becomes usable in a variety of tasks involving problem solving and comprehension only after it is reconstructed; that is, interpreted, enriched, and connected to the prior knowledge of the learner. Thus, learners must be active and constructive."* (Hatano & Inagaki, 2003)

Students bring naive conceptions about force and motion, developed through years of everyday interactions, to introductory courses in physics (Chi & Slotta, 1993; diSessa, 1993; Liu & MacIsaac, 2005; McCloskey, 1983; Wiser & Amin, 2001). Although there is general disagreement about the structure of those naive beliefs, research has demonstrated that they are robust and that traditional, teacher-centered instruction is largely unsuccessful in helping students to achieve a more expert view (Hake 1998).

Vosniadou (2007) argues that in order to move to an expert understanding of scientific concepts, students must undergo profound conceptual change. She suggests that instruction must address both the need for individuals to construct their own understanding and the sociocultural factors that are present in school settings. Still there is considerable disagreement on the exact nature of an instructional approach that may facilitate such strong conceptual change.

Some contend that misconceptions can be seen as resources for constructing understanding and that learning may involve refining and reorganizing prior knowledge fragments (Smith et al, 1993-1994; Hammer, 2000; diSessa, 1993) or validating both the everyday and scientific concepts to support students as they adopt the latter (Wiser & Amin, 2001). Others suggest that learning may involve challenging and replacing naive conceptions (McCloskey, 1983) or avoiding them in favor of a new, more expert view (Reiner et al, 2000).

Regardless of the true structure of naive conceptions, physics teachers in high schools are charged, every September, with beginning the process of developing Newtonian thinking with approximately one hundred students. Despite decades of research in physics education, success in this area has been limited (Dykstra, 2005).

In the field of Physics Education Research (PER), many empirical studies have demonstrated that carefully planned, interactive instruction can be effective in promoting a more expert, Newtonian view (see, for example, Crouch & Mazur, 2001; Hoellwarth et al, 2005; Kalman et al, 1999, 2004; Meltzer & Manivannan, 2002; Singh, 2005; Thornton & Sokoloff, 1998). Although specific approaches may vary, most successful interventions have included some form of peer collaboration in the instructional protocol. These findings support the view that instruction with a substantial component of verbal interaction among peers may help support strong conceptual restructuring or change.

Despite these findings many secondary science classes are still taught using a traditional, teacher-centered approach (Abi-El-Mona & Abd-El-Khalick, 2006; Angell, 2004; Newton et al, 1999). Interviews and surveys of instructors have revealed that their tendency to employ a traditional, teacher-centered approach may be due to their perception of time pressure due to curriculum requirements, their discomfort with leading classroom discussions (Newton et al, 1999), or a lack of sufficient pedagogical content knowledge (see, for example, Lee et al, 2007).

Part of the problems regarding the teaching and learning of Physics in secondary schools may be due to the fact that the majority of PER empirical studies have taken place at the college and university level, where many students may have already experienced formal physics instruction. Results of these studies may not easily translate into successful practices for beginning learners. There is also a dearth of studies on the mechanisms of conceptual change, with careful attention to the nature of student dialogues and the mechanism through which they may support conceptual change or restructuring. Such analyses are necessary if one wants to promote changes in the teaching of introductory physics courses at the secondary level.

This review of the literature will begin with a description of studies that explore the challenges faced by instructors as physics and other sciences are taught at the secondary level and of what studies have shown about the effectiveness of that instruction. This will be followed by a review of studies about teacher beliefs and pedagogical content knowledge and by a description of current curriculum and frameworks requirements and recommendations, aiming at exploring why traditional methods continue to be a predominant teaching strategy. The review will focus on empirical studies and theoretical positions that may help to explain the apparent failure of "traditional" physics instruction.

Next the review will examine some promising models of instruction that employ collaboration, including empirical studies from the field of Physics Education Research (PER) and other domains. The review will then consider theoretical frameworks that may help to explain the success of these interventions and will examine the literature regarding the explicit role that peer-to-peer dialogue may play in supporting conceptual restructuring or change.

Through this review I will argue that: (1) Both knowledge acquisition and conceptual change or restructuring may be needed for high school students to develop an expert view of Newtonian mechanics; (2) Peer-to-peer verbal interactions have an important role to play in fostering both knowledge acquisition and conceptual change or restructuring; (3) Combined quantitative and qualitative studies at the secondary level may illuminate whether peer-to-peer interactions can serve as resources for learning Newtonian mechanics; and (4) Careful analysis of interaction transcripts are needed to inform our understanding of how conceptual restructuring or change takes place.

The next section begins with an examination of studies depicting the challenges faced by instructors in secondary physics classrooms.

The Challenges Faced in the Teaching and Learning of Introductory Physics

> *"one of the most important missions of education is to enable students to understand ways of thinking of the various disciplines such as the physical sciences and mathematics. Yet, this is the area where schools fail most." (Vosniadou, 2007 p. 47).*

Vosniadou (2007) cites an overwhelming body of research that documents the failure of current teaching methods to promote expert understanding not only in the physical sciences, but also in other disciplines. She claims that this is the result of schools failing to deal explicitly with the problem of conceptual change. The studies described in next explore, in different countries and using different methodological tools, how instructional time is typically used in secondary classrooms, as a first step in examining why current instructional practices may fail to support the development of a Newtonian view.

For the sake of brevity instructional methodologies that are teacher-centered and lean heavily on teacher verbalization and demonstration, with students passively listening for a majority of instructional time, will be referred to as "traditional" methods. Instructional methodologies that favor a more active role for students, engaging them in dialog or other forms of interaction with peers for a significant portion of the instructional time available will be referred to as "interactive" approaches.

How is secondary physics typically taught?

Through a series of classroom observations and formal interviews with fifteen teachers in coeducational public schools in Perth Australia, Tobin &

Gallagher (1987) set out to determine what instructional activities were commonly employed in high school science classes. They found four common instructional modes: "whole class interactive, whole class non-interactive, individual and small group work." (p. 552). The most predominant mode (50% of observed class time) was described as whole class interactive: "when the teacher dealt with the class as a whole, and interacted with one student at a time while the others listened" (p. 552). Whole class non-interactive techniques, comprised of lecture-presentation or the use of audiovisuals, were utilized 20% of the time. The remainder of class time was taken up by individual seatwork and small group activities. The authors noted that: "Small-group activities occurred most often when students worked in teams to collect data in the laboratory. Small-group discussions occurred infrequently in all classes" (p. 553). As will be evident from the several studies that follow, this finding is not unusual.

A similar situation is described by Newton et al (1999) in schools in the London area. Using a designed observation protocol to quantify the types of activities employed in thirty-four lessons (including some in Earth Science, Biology, Chemistry, and Physics), from Year 7 through Year 11 (roughly equivalent to grades 7 through 11 in the United States), they found that:

> "'listening' was the dominant pupil activity in non-practical lessons (44%). Performing 'set exercises' and 'copying' together constituted a further third (32%) of the class time, nearly three times as much as was spent on 'open pencil and paper tasks' (13%). 'Group discussion' was notable in its absence " (Newton et al, 1999, p. 563).

When teachers were asked, in subsequent interviews, why discussions played such a minor role in instruction, they cited several reasons including the pressure of covering the National Curriculum and the challenge of managing classroom discussions.

Videotapes of lessons from eleven grade 8 and two grade 7 physics classes analyzed by Tesch et al. (2003) in German schools showed only very rigid and limited questioning strategies in classroom discussions with minimal student voicing of emergent understandings. The author inferred that teachers did not hold a constructivist view of learning.

In Norway, Angell et al (2004) administered a questionnaire to a random sample of grade 12 and 13 students taking physics (N=2192 respondents). Questionnaires were also sent to all physics teachers in every upper secondary school (N=342 respondents). Once the quantitative study was completed, a focus group study was conducted with grade 12 and 13 physics pupils (N=54). Most applicable to the current review, the authors found that approximately sixty percent of physics students surveyed reported that "very often" classroom time was spent with the instructor presenting new material on the blackboard (p. 700). Only five percent reported that discussions of difficult problems in groups was used "very often" although twenty percent expressed a wish that this strategy would be employed (p. 698). Overall, responding pupils expressed a desire for instruction to be more pupil-centered.

More recently, studies have explored whether additional resources, such as technological tools, might nudge classrooms toward a more interactive approach. Cuban et al (2001) employed teacher, student and administrator interviews combined with observations, reviews of school documents and surveys of both teachers and students in two high schools in the heart of Silicon Valley to determine whether access to technology (particularly computer technology) would lead to changes in teaching and learning. They found that although some changes in teaching style occurred when new technologies became more readily available, more often the technologies were adapted to fit in with familiar teacher-centered instructional approaches.

Abi-El-Mona and Abd-El-Khalick (2006) attempted to identify what types of arguments might naturally be fostered in typical lecture-discussion and laboratory activities in a secondary chemistry classroom. After observing nearly forty classes and six laboratory sessions, the authors only observed nine specific (and very brief) conceptual arguments. In follow-up interviews they found that, through the use of simple questions in which students were asked to justify their claims or beliefs, argumentation could be easily facilitated.

From these studies we see that teacher-centered instruction continues to be a widely used instructional strategy in secondary classrooms and, in a few studies, we hear that students have expressed a desire for more interactive environments.

In the next section we will examine several studies that sought to determine how traditional and interactive approaches compare with regard to student achievement in physics.

How Effective is "Traditional" Instruction?

Much of our knowledge of the effectiveness of traditional instructional methods in physics has originated from the field of Physics Education Research (PER). A few of those are summarized here, as illustrative of the overall pattern of achievement found when those approaches have been compared with more interactive modes.

Early in the 1980's it had become apparent to many university physics faculty members that introductory courses were not achieving their stated goals for understanding. Some researchers began to consider what factors might contribute to this lack of success. Champagne et al (1980) set out to determine if a university student's pre-instructional knowledge of mechanics and his or her mathematical ability and/or reasoning skills were correlated with successful learning of classical mechanics. Their pre-instructional assessment was comprised of three parts: an assessment of preconceptions about motion, a logical reasoning test and a mathematics skills test. Course success was measured by successful completion of mechanics questions on the final examination. Results from the pre-instruction assessment of preconceptions were far poorer than expected, despite the fact that many students had studied physics in high school.

In the final analysis, "mean student scores on the two hour exams and the mechanics portion of the final were only about 50% of the possible points in each instance" and the authors concluded that: "mastery of elementary mechanics presents a formidable challenge" (p. 1076). No significant correlation was found between scores on the logical reasoning pre-test and achievement in mechanics.

A detailed examination of student responses showed that many students, despite prior formal instruction in physics, held a surprisingly naive view of force and motion and the authors proposed that: "instruction in classical mechanics can be improved by continuously encouraging the students to reject an Aristotelian system of beliefs and to adopt a Newtonian paradigm" (p. 1076).

In the early to mid 1980's a flurry of studies were published with consistently similar findings (see, for example, Clement, 1982 and Whitaker, 1983). A clarion call came from Halloun and Hestenes (1986) through their work in the development of an assessment instrument, The Mechanics Diagnostics Test (later known as the Force Concept Inventory-FCI). The authors set out to determine if students' initial, common sense beliefs about force and motion had a significant effect on their performance in introductory physics. Pre- and post-testing was conducted with nearly 1500 students at Arizona State University and another 80 students at a nearby high school. The format for these courses was typically lecture-recitation with approximately 3 or 4 hours of lecture and 1 hour of recitation per week. Among other findings the authors reported a devastatingly small (14%) gain from conventional instruction and suggested:

"throughout the course the students are operating with a seriously defective conceptual vocabulary, which implies that they continually misunderstand the material presented" (p. 1048). The FCI provided instructors with an assessment tool that was powerful and easily administered.

Subsequently Thornton & Sokoloff (1998) described the development of a "research-based, multiple-choice assessment of student conceptual understanding of Newton's Laws of Motion" called the Force and Motion Conceptual Evaluation-FMCE (p. 338). The authors administered FMCE items to 240 noncalculus 'NOLAB' students at the University of Oregon during 1989 and 1990, before and after traditional instruction that included "standard lectures, homework problems, quizzes and exams" (p. 339). Results showed that: "less than 20% of the students answered dynamics questions in ways that are consistent with a Newtonian view of the world, either before or after instruction" (p. 339). Although these were university students, many of whom had studied physics at the secondary level, few entered the course with a Newtonian view and the course had little effect in promoting one.

Fast-forward nearly twenty years to when Dykstra (2005) shared the dismal findings of pre- and post-test results (both algebra-Trig and Calculus-based courses) between 1990 and 2002. For courses using a traditional approach typical normalized gains on the Force and Motion Conceptual Evaluation (FMCE) from the study ranged from 9% to a maximum of 26%. Because the pre-test scores were low, such a small, normalized gain indicated that the courses had been minimally effective in moving students to what Dykstra describes as a "New View" of force and motion.

These studies and others demonstrate that traditional methods are not sufficient to support conceptual change or restructuring, at least in introductory physics courses. The following studies will explore why, despite the widespread dissemination of these empirical studies, traditional instruction may still be so prevalent in secondary physics classrooms.

Why are teacher-centered methods still used?

Given the evidence of commonly poor results from "traditional" instruction, why so little has changed in most introductory physics classrooms? Several possible reasons are considered in the studies reviewed below.

Strauss (1993) suggested that teachers might be unaware of their in-use mental models of teaching and learning. He attempted to examine teachers' attitudes toward learning modalities and concluded that: "When we teach alternative models, such as those of Piaget and Vygotsky, teachers do not realize we are presenting alternatives because they do not know they have models that serve as the grounding against which the alternatives exist" (Strauss, 1993, p. 287). These findings may explain why many teachers, who have been introduced to constructivist and socio-constructivist theories of learning and development in educational methods courses, may still teach in a way that reflects reliance on a model of transmission and consumption of knowledge. This may reflect an in-use model, possibly developed over the course of their own experience as learners. Other studies, as summarized below, have examined the need for physics teachers to develop not only content knowledge but also pedagogical content knowledge.

McDermott et al (2000) faults the training that pre-service teachers receive in university settings. She reports that pedagogical training often takes place in methodology courses, and is divorced from the content: "The separation of instruction in science from instruction in methodology decreases the value of both for teachers" (p. 416). She suggests that, as a result, teachers are not able to apply their pedagogical knowledge to the physics content in ways that might foster understanding in their students and calls for a more integrated model for the training of pre-service physics teachers, a proposal similar to the idea of promoting pedagogical content knowledge (PCK), developed and described by (Shulman, 1986) as a combination of content and pedagogical knowledge. Yet, even if the instructional model in teacher education programs was more integrated, it may take several years for teachers to internalize what constitutes effective teaching at the secondary level, as Lee et al (2007) suggest.

Lee et al (2007) define PCK as "the knowledge that science teachers use to facilitate students' understanding of scientific concepts and to encourage their scientific inquiries" (p. 52). It was expected that individual teacher's PCK influences the level to which teachers provide their students' with structured opportunities to construct their own knowledge (individually or through social processes). To explore the PCK of beginning teachers, Lee et al (2007) developed an interview protocol and employed it to compare teachers in four different induction programs (e-mentoring, general, intern and science-specific). The elements of PCK examined included: Prior Knowledge, Variations in learning, Misconceptions, Scientific inquiry, and Representations. A careful analysis from the pre- and post-test data determined that initially 76% of teachers were in the *limited* level and 24% in the *basic* level with regard to their pedagogical content knowledge. The post-test data showed that 65% of teachers remained in the *limited* level and 34% were found to still be in the *basic* level, with only 1% achieving the *proficient* level" (p. 56)

The authors concluded that most beginning secondary science teachers have very limited levels of PCK despite their science backgrounds and that induction programs have a minimal effect on its development. They theorized that a teacher's PCK must be constructed, through experience in the classroom, while the teachers themselves are making important instructional decisions based upon the learning of their students and through collaboration with more experienced colleagues.

Given these findings, it may take some teachers years to develop sufficient pedagogical content knowledge to effectively support students in ways that help them to develop a more expert, Newtonian view. In addition to limitations in teacher preparation models, the pressures of broad-based curriculum requirements might influence the choice of instructional delivery modes employed, as we see below.

It is possible that teachers in real classrooms must compromise their ideal view of teaching and learning due to the realities of the demands they face in real classrooms. Teachers interviewed by Newton et al. (1999), clearly expressed that pressures of curriculum "coverage" influenced their pedagogical decisions with regard to employing argumentation and/or discussion in the classroom.

In fact, a look at state learning standards reveals that students in an introductory course should master not only Newtonian mechanics, but also develop an understanding of Heat and Heat Transfer, Waves, Electromagnetism and Electromagnetic Radiation (Massachusetts Department of Education, 2006, p. 74-75). These are the minimal requirements of an entry-level, introductory course. Honors and Advanced Placement courses would require more depth in these topics, as well as more breadth in the overall course. The pressure of delivering such comprehensive curriculum requirements in an introductory course would likely inform the choice of instructional format and present an obvious dilemma for reflective practitioners. If students are not allowed to grapple actively with concepts in the classroom, conceptual understanding is likely to be fragile at best. Yet, if instructors allow their students significantly more time to pursue a thorough understanding of fewer topics, students may not meet the requirements of the learning standards for the course.

In addition to the breadth of content typically required in an introductory course, curriculum standards rarely explicitly promote collaborative or interactive methods as an important mode of instruction. Rather, an emphasis on students' active exploration of the physical world seems to be the focus when instructional modes are recommended.

National and local curriculum standards emphasize (and therefore assess) independent inquiry methods; they do not endorse (at least not explicitly) argumentation or discussion. The emphasis on inquiry would suggest to teachers (and their evaluators) that the inquiry process should play a major role in instruction and will necessarily result in improved understanding of conceptual ideas. In reality, it is possible for students to complete laboratory investigations, expressing scientifically appropriate conclusions, without having truly considered how those concepts fit with their current understanding of physical events in everyday life.

> "Although a 1988 College Board survey of introductory college physics courses showed that approximately 80% of lab experiences in those courses were of the cookbook variety, it is well known that such labs lead students to describe their lab work as 'boring' or a 'waste of time'... The American Association of Physics Teachers has compiled advice, including the importance of using labs to further conceptual learning".
> (Gollub & Spital, 2002, p. 52)

In the United States, "A Nation at Risk: The Imperative for Educational Reform" warned that "the educational foundations of our society are presently being eroded by a rising tide of mediocrity that threatens our very future as a Nation and a people" (National Commission on Excellence in Education, 1983, p. 1). With regard to science education, at the high school level, the report called for instruction that included: "a) the concepts, laws and processes or the physical and biological sciences; b) the methods of scientific inquiry and reasoning; c) the application of scientific knowledge to everyday life; and d) the social and environmental implications of scientific and technological development." (National Commission on Excellence in Education, 1983, Recommendations).

The report resulted in a flurry of educational reform efforts at the national (a recent example is the No Child Left Behind Act) as well as state and local levels where curriculum frameworks were established and high stakes testing implemented to drive instructional improvement. A closer look at the Massachusetts Science and Technology/Engineering Curriculum Frameworks reveals standards requiring that "The curriculum should include substantial hands-on laboratory and field experiences, as appropriate, for students to develop and use scientific skills in introductory physics, along with the inquiry skills listed below" (Massachusetts Department of Education, 2006, p. 76).

The inquiry strand prescribes the skills students need to conduct a scientific investigation and to analyze and communicate the results of that investigation. These learning standards are followed by a section entitled 'What it looks like in the classroom' depicting an investigation designed to help students develop an understanding of the concept of acceleration. Although the sample lesson includes a series of questions and answers between the teacher and individual students, in a whole class setting, followed by an empirical investigation of the motion of an accelerating car, no time is explicitly allocated for student discussion of the concept or of their empirical findings. These standards do not suggest that peer-to-peer discourse and/or argumentation are key or helpful pedagogical techniques to further students' understanding.

Even if, despite the lack of emphasis on discussion and argumentation in the frameworks for science teaching, instructors make a commitment to an interactive approach, implementation of these methods may present other instructional challenges, as we will see below.

Hammer (1995) looked closely at student conversations in a physics classroom and noted the tension instructors may feel between supporting students' interactive inquiry and the concerns of traditional teaching. He noted:

> "Introductory physics teachers have accepted theories in mind, and evidence of progress toward those theories affects their views of the success of a class. Such concerns, however, often conflict with concerns for students' participation in a process of inquiry. Students need to be willing and comfortable to take risks by expressing their ideas. If a teacher routinely corrects their thinking, they learn to keep their thoughts to themselves" (p. 426)

As we have seen, despite evidence to support interactive engagement, there are many reasons why many physics teachers may continue to rely on traditional, transmission-based approaches. The next section will focus on why traditional methods may be unable to support the kind of conceptual restructuring or change that is needed to become a Newtonian thinker.

Why might "traditional" instruction fail?

In the realm of formal physics instruction, patterns of retaining underlying though incorrect beliefs have been the norm for decades as traditional approaches to teaching continue to be used. Many reasons have been proposed for the failure of traditional instruction.

Among them it has been proposed that:

1) Students arrive in a first course in physics with firmly held, naive beliefs about force and motion.

2) Traditional, teacher-centered instruction may not fully engage students in knowledge construction in the classroom.

3) Without fully engaging in articulating and defending current beliefs, students may not question their accuracy or coherence.

4) Although students may overtly comply with the authority of formal instruction in responding to assessment items, their underlying belief structures may remain unexamined and unchallenged, and their conceptual framework will remain essentially unchanged, even after "successful" completion of their introductory course.

This section will explore why traditional, teacher-centered instruction may be ineffective for novice physics students. To do so, it will be important to, first, consider theories of conceptual change. Second, one must consider students' typical misconceptions.

Theories of conceptual change. To become Newtonian thinkers, both knowledge acquisition and conceptual change or restructuring are needed. Students must acquire some knowledge (including vocabulary and symbolism) commonly used in the solution of mechanics problems. They must also substantially restructure, revise or wholly reject and replace some of their naive beliefs about the relationship between force and motion to adopt a more expert view.

Carey and Spelke (1996) addressed the difference between knowledge acquisition and conceptual change as less than distinct. They acknowledged that many questions that remain about how conceptual change takes place, saying that it would be difficult for "a person who reasons within the context of one system of knowledge to discover entities and relations beyond that system." (p. 526). They proposed that conceptual change must arise from "new mappings across systems of understanding" (p. 528). Although they admit that not all conceptual change necessarily results from such efforts.

To explore why traditional methods may not achieve strong conceptual change or restructuring, it will be important to first consider the nature of the naive beliefs students are likely to hold upon entering an introductory course at the secondary level.

There are multiple theories concerning the nature of naive physics beliefs. Some would suggest that there is little coherence among naïve beliefs, with students relying on multiple, incoherent, primitive understandings of phenomena that would be more clearly correlated in an expert's view (see, for example, diSessa, 1983, 1993, 2004; Minstrell & Stimpson, 1996). Others have proposed that a novice's beliefs have a more coherent or theory-like structure (see, for example, Kaiser et al., 1986; McCloskey, 1983; Chi & Slotta, 1993; Reiner et al., 2000; Ioaniddes & Vosniadou, 2000, Wiser and Amin, 2001). Consider briefly the theoretical perspectives of five of these authors:

diSessa (1983) coined the term p-prims (phenomenological primitives) to describe the collection of naive beliefs expressed by his subjects during interviews about the underlying principles in a variety of physical situations. He claims that a lack of structure of 'physics-naïve' people's understanding of force and motion makes them incapable of making a "strong, principled commitment to a particular interpretation of a physical phenomenon" (p. 33). In contrast, McCloskey (1983) found this naïve physics knowledge to be more coherent and theory-like. He noted, in his subjects, a shared understanding of the relationship between force and motion that closely resembled the historically held belief in the notion of *impetus*. In impetus theory, an applied force provides an object with an acquired force or *impetus* that then dissipates over time. Reiner et al. (2000) agreed that physics novices demonstrated a knowledge that was somewhat coherent and suggested a more general reliance on interactions as properties of substances and that misconceptions were more likely due to ontological incoherence. In particular, with regard to mechanics: "Novices tend to explain forces and constraints as internal properties of moving objects or as the intentional interference of some external agent"(Reiner et al, 2000, p. 7). According to Wiser and Amin (2001) one of the reasons students may be unable to revise their naive beliefs is because "students and scientists may use the same terms for different conceptual referents and that scientific conceptions can account for everyday ones" (p. 331). And Vosniadou (2002) argued that: "children start the knowledge acquisition process by organizing the multiplicity of their sensory experiences under the influence of everyday culture and language into narrow explanatory frameworks that are different from the currently accepted science" (Vosniadou, 2002, p. 61). In contrast to the "knowledge in pieces" theory, she suggested that children's knowledge, in fact, comprises a system of information, mental representations, sensory information that is quite complex. When new information is attained through experience or formal instruction, that knowledge is assimilated into a system that is inconsistent and quite different from an expert's understanding, resulting in 'synthetic' models of physical behavior.

Each of these five theoretical proposals would suggest a different approach to instruction. McCloskey's perspective led to a suggested replacement model, requiring: "physics instructors to discuss with students their naive beliefs, carefully pointing out what is wrong with these beliefs and how they differ from the views of classical physics. In this way, students might be induced to give up the impetus theory and accept the Newtonian perspective" (McCloskey, 1983, p. 319). Reiner et al (2000) suggested a fresh start in which "materialistic models should be avoided altogether in teaching such concepts. In these cases, instruction should attempt to introduce a new language of processes while shunning any language that uses the ontological attributes of material substances. This could be achieved by making use of visual simulations and tailored instruction about the *process* category to help expose students to novel ontological attributes (e.g. simultaneity, independence, or equilibrium-seeking)" (Reiner et al, 2000, p. 30). From the knowledge in pieces perspective, diSessa (1993) proposed that conceptual change in physics is marked by the "reuse and integration of intuitive knowledge structures into the functional encoding of, for example, a physical law" and that "The depth, breadth, and integration of the expert's priority network marks a major change from intuitive physics." (p. 115). The findings of Vosniadou et al (2001) would suggest that conceptual change can be supported by classroom environments which allow students to express and support their own ideas and to test them by conducting experiments. Other important components in their proposed instructional model include an emphasis on small group work and classroom debate as well as opportunities to use models, representational symbols and measurements. Wiser and Amin's (2001) findings support the proposal that instruction must explicitly address and validate both the student's naive conceptions and the scientific concepts under study in order to facilitate conceptual restructuring or change.

Regardless of one's commitment to a particular structure for student's naive conceptions about how force and motion relate, it is clear that these beliefs must be explicitly articulated and, in some cases, challenged. We have seen that this cannot be accomplished through a transmission mode of teacher-led instruction. Rather, students must be active participants in this challenging cognitive work. Instruction must allow students an active, constructivist role in the process.

Students' typical misconceptions. In addition to describing the overall structure of students' naive physics beliefs, researchers have catalogued many very specific misconceptions commonly held by students. For readers who may be interested in an extensive review of such misconceptions, see Duit (2007). For the purpose of this review, consider, for instance, the misconceptions held by students in the area of kinematics and dynamics described next.

With regard to kinematics, students often confuse or do not distinguish among the quantities position, velocity and acceleration in the algebraic and graphical analysis of motion (Trowbridge & McDermott, 1980; Whitaker, 1983). They may fail to recognize that an object traveling with constant speed, but changing direction, is undergoing acceleration. When objects reverse direction, students have difficulty representing the correct velocity and acceleration vectors at the turnaround point (Shaffer and McDermott, 2005). With regard to uniform circular motion, students may fail to recognize that the instantaneous velocity of an object as it travels a circular path is tangential (Shaffer & McDermott, 2005).

In the area of dynamics, students will often assume a force in the direction of motion when none exists (Gunstone, 1987; Champagne et al, 1980; Clement, 1982) and believe that an object will decelerate if no force is applied, even if the situation is explicitly described as frictionless (Halloun & Hestenes, 1985). Students often believe that an object's speed changes in response to either an increase or dying out of force (Whitaker, 1983; Clement, 1982; Gunstone, 1987; Champagne et al, 1980) and that there is a linear relationship between velocity and force, rather than force and acceleration (Champagne et al, 1980).

Many students believe that forces impart impetus to an object that then dissipates over time. Some believe that gravity does not begin to act on an object until its impetus has dissipated. In addition, some describe that objects traveling along a circular path are imbued with a circular impetus that dissipates once they leave their circular restraint (McCloskey, Caramazza & Green, 1980; Halloun & Hestenes, 1985; McCloskey, 1983; Champagne et al 1980).

Students may confuse the net force with the net acceleration and may not associate the direction of the net force with direction of the acceleration (Shaffer & McDermott, 2005). Many believe that a heavier weight causes a bigger acceleration in freefall or that gravity is significantly different at relatively minor elevations above the earth's surface (Gunstone & White, 1981; Minstrell, 1982).

These are just some among the multitude of misconceptions that have been catalogued by PER, and are restricted only to a small portion of the mechanics curriculum. In addition to neglecting to explicitly address students' naive conceptions, there are other possible reasons for the lack of success typically seen in teacher-centered instruction. One may simply be that such instruction does not engage students in the difficult but necessary cognitive work.

Clearly, to do the difficult cognitive work required to achieve Newtonian thinking, student engagement is a prerequisite. A lack of engagement in instruction may contribute to the ineffectiveness of traditional introductory courses. Yair (2000) hypothesized that various instructional methods may contribute differentially to the level of student engagement in the classroom. He reported findings from a study in which students were given digital watches programmed to beep eight times during the day (from 7:30 am to 10:30 pm). When their watch beeped, students were asked to respond to a short questionnaire about what they were doing, thinking and feeling at the time of the beep. The data included information from 865 students reporting 28,193 daily experiences. He found that:

> "students' engagement with instruction varied with instructional method. The highest rates of engagement were for work in laboratories (73.7 percent), work in groups (73 percent), individual or group presentations (66.7 percent), and discussions (63.1 percent); the lowest were for teachers' lectures (54.4 percent) and television or video presentations (55.9 percent). Thus, different instructional methods engage students to various degrees, although they do not differentially affect the type of alienation from instruction." (p. 256).

Yet, even for students who do engage in the presentations offered by instructors, an overt compliance with authority may mask an underlying reliance on prior, naive beliefs. Vosniadou (2003) described the knowledge gained in typical instructional settings in this way: "Conceptual change in school settings is often associated not to reasoned change but to compliance to the authority of the teacher or the textbook" (p. 402). Students may be capable of responding correctly to questions and/or solving quantitative problems without fully assimilating expert concepts into their personal system of beliefs. This articulated "knowledge" is likely to be fragile and carefully constructed questions, centered on important conceptual underpinnings, may unearth an underlying reliance on less expert ideas as students think about physical phenomena in everyday settings. The following anecdote may serve to illustrate this reliance on authority.

For many years, Eric Mazur had been teaching introductory physics to Harvard undergraduates through "'traditional lecture' type of presentation, enlivened by classroom demonstrations" (Mazur, 1992, p. 539). After reading a journal article summarizing the poor results achieved, after instruction, on a conceptual assessment (Halloun & Hestenes, 1985) he decided to administer the test to his own students. He was astonished when a student asked, "Professor Mazur, how should I answer these questions? According to what you taught us, or by the way I think about these things?" (Mazur, 1992, p. 140). Although his students were adept at solving complex quantitative problems in physics, they scored poorly when their conceptual understanding was assessed. In spite of direct instruction and strong, positive feedback from his students, they continued to hold, at best, parallel and more often contradictory beliefs about force and motion.

In addition to the existence of naive understandings and students' tendency to acquiesce to the authority of an instructor, a lack of opportunity to construct their own knowledge may underlie students' lack of success in traditional courses.

As Dykstra (2005) states, regarding the components of his successful, constructivist approach:

> "For the radical constructivist, communication is the individual construction of meanings to be associated with symbols and combinations of symbols from someone else ... Through copious interaction with 'others,' we develop look-up tables that work sufficiently well that we can take our own look-up table as shared with 'others'." (p. 56).

These descriptions of teaching strategies echo diSessa's notion of the development of understanding:

> "I approach intuitive physics as an expression of an underlying sense of mechanism that occasionally exhibits relatively uniform results, but on the whole lacks important systematicities of theoretical science. As such, it does not need to be replaced so much as developed and refined." (diSessa, 1993, p. 109).

In a teacher-centered approach, there is little if any opportunity for students to articulate their current beliefs, hear what others are thinking and examine those ideas for their ability to reliably predict the behavior of objects in the physical world. At best, questions posed by instructors to individual students may be the limit of interaction in some classrooms. Remaining members of the class are not required, in this model, to subject their own ideas to the type of scrutiny that might elucidate any incoherence in their mental models.

Regardless of educators' characterization of students' naive views about physical phenomena or about how a student's shift toward scientific conceptions might develop, the practical challenge in education consists of finding instructional methods that would help students to understand and adopt current scientific views. Members of the Physics Education Research (PER) community and researchers in other disciplines have found that instructional interventions that include a component of peer-to-peer interaction have been effective in supporting knowledge construction. Some of these studies are examined next.

Promising Approaches in Teaching and Learning Introductory Physics

Much of the research on alternative instructional methods has focused, at least in part, on employing interactive methods as the way to promote better science learning.

What Alternative Instructional Methods Have Been Proposed, and to What Effect?

Modeling. Wells et al (1995) described a "modeling method" of instruction with a focus on student-designed inquiry. In modeling, instruction begins with the presentation of a physical situation which students are asked to describe. This descriptive portion of instruction culminates with students identifying measurable characteristics that might describe the behavior of the system. A classroom discussion helps students to focus on the important issues in experimental design to test relationships in the behavior of the system. Students then design and conduct an experiment of their own design, and record their findings in a lab notebook. In the next stage, students employ their new understanding to solve additional problems. Problem solutions are then shared through presentation by individual groups to the entire class.

In the summers of 1990 and 1991 a group of high school physics teachers participated in modeling workshops as proposed by Wells et al. (1995) in preparation for using this approach in their own classrooms:

> "By the usual anecdotal measures the program was a great success. However, the *Force Concept Inventory* gave us an objective measure of gain in teaching effectiveness by comparing the score of each teacher's class just before the workshop with one just after. The result was a sobering 4% -- barely significant!" (Well et al., 1995, p. 617).

The authors continued to refine the modeling implementation and in the following summer achieved, in their words, moderate success with a slightly higher gain of 22%. Although large group discussion and problem presentation were employed in this intervention, substantial use of collaborative work in small groups was not the major focus.

Microcomputer-Based Labs and Interactive Lecture Demonstrations. Thornton & Sokoloff (1998) developed interactive laboratory and lecture demonstration methods that shared the goal of increasing student interactions to improve achievement in physics. Through the use of microcomputer based laboratory activities (MBL) and Interactive Lecture Demonstrations (ILD's) students were invited to predict the behavior of physical systems, and to discuss those predictions with a peer. Finally, sensor based technologies were used to demonstrate the concept under study through physical demonstration. The authors found significantly improved conceptual understanding (as measured by FMCE scores), and stated that "the total gain of over 75% from before instruction should be compared to the 7% to 10% gain we have seen resulting from traditional instruction" (p. 344). Although participants were both high school and college students, the authors reported that their most "extensive controlled testing" took place at the University level.

It is clear that the work of Sokoloff and Thornton employs peer-to-peer interactions as only part of an overall instructional protocol that also focuses on empirical investigations and/or demonstrations. Nevertheless peer discussions (in lab groups and during interactive lectures) are a key component of their instructional methodology.

Peer Instruction. In the Peer Instruction approach described by Crouch & Mazur (2001), lectures to undergraduate students are interrupted for the purpose of posing challenging, multiple-choice conceptual questions. Students are required to respond individually, via an electronic polling device. They are then directed to discuss their initial response with a peer and finally to respond again. A histogram is displayed and used to inform the instructor about next steps.

Immediately upon implementation of these methods, and independent of instructor, students in Peer Instruction classes achieved significant gains on the

FCI (g = 0.49) over those taught through a more traditional, lecture-based approach (g = 0.25). Although Mazur's approach to interaction was clearly defined, the generality of his findings are limited given that his student sample represented a very select group of students (Harvard undergraduates), many of whom may have had previous instruction in physics.

A main focus of the intervention was to allow students an opportunity to articulate and discuss their current conceptual understanding with a peer. This requirement to commit to a response and defend that response is lacking in traditional, teacher-based classrooms where questioning, if present at all, takes place between the instructor and only a handful of students. Although the authors acknowledge making other changes to the course, including the use of warm up exercises and the implementation of "Tutorials in Introductory Physics" (McDermott et al, 1998) in recitation sections, it seems clear that a major component of the success of this method lies in the use of collaborative discussions in the lecture classroom.

In another, similar intervention Meltzer & Manivannan (2002) attempted to make lecture-based instruction more closely resemble tutorial methods in their introductory courses at the university level. They wrote carefully sequenced questions for each lesson, emphasizing qualitative reasoning, and students responded using flashcards. Because this new method was more time-intensive, they reduced the content of the course, replaced their traditional text with an instructional workbook of their own design and implemented tutorial sessions.

The authors reported a normalized gain on the Conceptual Survey of Electricity (CSE) of 0.46 to 0.69 for this new, interactive approach (compared to a typical gain of 0.25 from more traditional courses (p. 648). Because several course changes were made, simultaneously, improved student achievement could not be attributed to any one intervention. It is clear, however, that peer-to-peer interactions played a significant role in the classroom protocol.

Whole class discussion. Nicol and Boyle (2003) contrasted Peer Instruction methods as implemented by Mazur et al. to one that included a whole-class discussion technique. In the whole class alternative, a conceptual question was posed. Students discussed the question in small groups, finally responding individually using an electronic polling system. A histogram displayed the class consensus, at which point, students explained and defend their answers in a whole class discussion format. Finally, the lecturer summarized and explained the "correct" response.

The main difference in this method is the utilization of whole class discussion (absent in the Mazur method). To explore students' perceptions and motivations the authors relied upon semi-structured interviews with a sample of 25% of the entire cohort, a survey completed individually and a "critical incident questionnaire" given to students during an interactive session in which both methods were utilized. Interviews and surveys showed that "all students reported that the teaching methods used in the wired classroom helped them to improve their understanding of difficult concepts when compared with conventional lecture classes." (p. 465).

When asked to explicitly compare peer discussion with whole class discussion "peer instruction was perceived by students to be more beneficial to learning than class-wide discussion" (p. 470). Students expressed that the initial step in peer instruction gave them the opportunity to "formulate an individual interpretation of the concept in relation to the test question." It is possible that, in this first step, students began to create their own mental model of the physical situation in the question. According to student responses, subsequent peer discussion enhanced this constructive process as they attempted to "convince your neighbors that you have the correct answer" (p. 470). From a student perspective, knowledge construction appears to begin individually, and to be significantly enhanced through the collaborative process.

In an attempt to refine Peer Instruction methodology, Reay et al. (2005) employed a three-question sequence in which all three questions focused on the same idea, but involved different contexts, and different levels of difficulty. The first question was designed as a simple warm-up and to build confidence. The second question was more difficult and significant fractions of students chose different answers. The final question was used to determine whether, after discussion, students correctly understood the concept and to inform the instructor about appropriate next steps.

The authors found that the three-question sequences appeared to help students assimilate concepts quickly, although they suggested that further study is needed to determine long-term effects. Attitudinal surveys found that students were overwhelmingly in favor of the use of interactive technology in the physics classroom. Other approaches have also employed interactions in empirical investigations to support understanding.

In a mathematics task administered to low achieving high school students, Schwarz et al (2000) found that even two students whose initial responses to the task were both incorrect could, through peer interaction, achieve a more correct response. When participants disagreed (although both were incorrect), discussion led them to state their initial arguments. This argumentation led them, in some cases, to infer new rules or, in others to participate in active hypothesis testing using a calculator. The authors concluded: "the study of the 'two wrongs make a right effect' may allow educators to facilitate cognitive gains among peers interacting around instructional tasks."

Studio style instruction. Hoellwarth et al. (2005) reported findings from employing an instructional model called "studio-style" which set out to eliminate the boundary between the classroom and the laboratory. Active learning approaches were employed, including "RealTime Physics: Active Learning Laboratories" (Sokoloff et al, 1999) and "Interactive Lecture Demonstrations" (Sokoloff & Thornton 2004). Class time was largely utilized in two ways: computer-based lab activities and small group collaborative work.

Simultaneously, at the same university, traditional classes were taught with a much clearer distinction between lecture and laboratory components.

The FMCE was utilized to measure the gain in conceptual understanding for both groups. The study was conducted over the course of three different quarters and instructors were varied, to minimize the effect of the instructor. The studio-style course realized average normalized gains of 0.65 on the FMCE while the traditional courses achieved only an average normalized gain of 0.21. Additional assessments of students' ability to solve quantitative problems suggested that the achievement of these conceptual gains did not come at the expense of such quantitative abilities. Although this intervention leaned heavily on laboratory investigations, collaboration played a key role as the majority of instructional time was utilized either with laboratory activities or small group collaborative work.

Tutorial methods. Researchers at the University of Washington attempted to add a tutorial component to instruction to strengthen understanding. Shaffer & McDermott (2005) described an investigation into the way that university students understand velocity and acceleration as vector quantities in one and two dimensions. One goal of the study was to develop a set of instructional materials utilizing a tutorial approach. Each tutorial is part of an instructional sequence that includes a pretest, a worksheet, a homework assignment and a post-test. In tutorial sessions, the "Structure is provided by worksheets with sequenced questions designed to guide students, working collaboratively in groups of 3-4, through the reasoning required to develop a functional understanding" (p. 922). The study encompassed the work of more than 20,000 students, mostly undergraduates at nine US universities who served as pilot sites for the curricula. Another 200 students were enrolled in courses for K-12 teachers.

The study provided evidence of the persistent difficulty many students have with kinematics. In some cases, these were related to an inability to perform basic vector operations. However, in many cases, the difficulties were of a more conceptual nature, involving the operational definitions of velocity and accelerations. The tutorial approach "has not only helped the introductory students for whom it was expressly designed, but also helped undergraduate and graduate TA's both deepen their own understanding and recognize the difficulties inherent in this topic" (p. 930). The tutorial approach focuses on instructional guidance in the form of worksheets, but its main instructional delivery mode is small group collaboration.

Ambrose (2004) reported the findings from an ongoing research program in the junior-level course in intermediate mechanics at Grand Valley State University. The goals of the intervention were to address difficulties relating velocity and acceleration, to improve skills in drawing free-body diagrams, and to promote understanding of Newton's second law. The tutorial procedure was modeled after *Tutorials in Introductory Physics* (McDermott et al, 2002) and described as follows:

> "At the heart of the tutorials are carefully structured worksheets that guide students through the reasoning necessary to overcome specific difficulties identified by research. Students work collaboratively through the tutorials in small groups, and the instructor teaches by questioning rather than by telling" (p. 458).

Results from pre- and post-testing showed that undergraduate students enrolled in the tutorial sessions consistently outperformed physics graduate students ("65% correct versus 15% correct") at other institutions "after traditional undergraduate instruction" (p. 458). Although the tutorial intervention was not solely based on peer-to-peer interactions, collaborative group work played an important part in the implementation and collaborative discussion is a critical tool in the protocol.

As we have seen in the above review, many of the successful curricular interventions in PER rely, at least in part, on small group collaborative work. However, the majority of this work was developed with college students and very few, to date, can be found on the use of interactive methods in Physics classes at the pre-college level. The available research on interactive methods with younger populations, however, has been done in other content areas, as detailed below.

Dyadic discussion. Kuhn et al (1997) set out to test the hypothesis that "engagement in thinking about a topic enhances the quality of reasoning about that topic". (p. 287). Participants were an ethnically diverse group of students from an urban community college and an urban, pubic middle school in the same city. They were given a pre-test soliciting their opinions and reasoning about the issue of capital punishment and, over the course of several weeks, the experimental group participated in a series of dyadic discussions about this topic, while the control group did not. Six weeks later, both the experimental and control groups participated in a post-test assessment. The authors examined the qualitative change in reasoning from pre-test to post-test for each group, finding that "progressive change was the modal pattern for experimental participants" while "Regressive change (decline) was the most frequent outcome for control participants, but no-change and mixed patterns were also common." (p. 300). The most common improvement in reasoning came in the form of metacognitive statements, followed by shifts from one-sided to two-sided arguments. A second study, similar in design but more limited in scope, achieved equivalent results.

In summary, educational research in physics as well as other domains has proven that pedagogical methods that engage students in interactive discussions of conceptual ideas can be more effective than traditional, lecture-based methods of instruction. Many different approaches have been proposed, including peer discussion techniques, microcomputer-based laboratory activities and interactive lecture demonstrations and interactive tutorials. Although there are subtle and, in some cases, significant differences in these approaches all rely to some extent on student dialogue as a tool to support the construction of knowledge.

Much of the research in physics education has taken place in college and university settings and without always making a distinction between students who have had prior instruction in physics. Few have focused on the secondary level and only a handful has carefully examined the nature of peer-to-peer interactions as a mechanism for improved conceptual understanding.

Studies on science learning building on peer interaction are still needed among younger populations. Such studies should clearly define interactive methods as relying on "peer-to-peer" discussions of challenging conceptual issues and include the systematic analysis of student dialogues to clarify how peer interaction may lead to changes in students' views. The planning, refinement and interpretation of the results of such studies will benefit for theoretical perspectives on human development and learning. In the following section, we will examine how theories of conceptual change, and teaching and learning can inform our understanding of the success of interactive methods.

What Theories May Explain the Success of Interactive Methods?

The use of peer interactions in the teaching and learning of Newtonian mechanics is supported by a socio-constructivist theory of learning and development. This section will address what is meant by conceptual change and how educational theorists view the processes that are necessary to promote such change.

Conceptual change has been described from different perspectives. For instance, Carey (1985) clearly differentiated between weak and radical conceptual restructuring. In weak restructuring, there is no change to the core of a theory and this type of change does not require that one eliminate existing beliefs or misconceptions. However, when learners are faced with information that cannot be reconciled with existing beliefs, a radical restructuring is required. Vosniadou (2003) considers conceptual change as "the outcome of a complex cognitive as well as social process whereby an initial framework theory is restructured" (p. 377). Ferrari and Elik (2003) describe the standard model of conceptual change in cognitive science as distinguishing between "routine learning and deep or radical conceptual change" (p. 33). In this conception, regular learning involves accretion of new knowledge onto an existing framework while radical conceptual change involves a change in "the ontology or essence of the concepts themselves" (p. 33). For DeLeeuw & Chi (2003), "*Radical conceptual change* involves completely replacing old concepts with new ones, because the target scientific concept is incompatible with the existing "folk" concept" (p. 73).

Whether one subscribes to the notion of restructure or complete replacement of concepts, it is clear that Newtonian thinking requires some manner of radical conceptual change. A historical perspective of conceptual change theories may be helpful in considering how this could be achieved.

Among the earliest educational philosophers, Rousseau recognized that adolescents are developmentally unique, being able to "keep more than one thing at a time in mind, and even compare and reason about the phenomena within his experience" (Rousseau, 1956, p. 69). He suggested that students will learn the natural sciences through exposure to them and that the role of the teacher is to arouse curiosity, but to leave the solution of a problem to the student alone. "Do not teach him science: let him discover it" (Rousseau, 1956, p. 73).

John Dewey disagreed with a strictly discovery approach to instruction, saying that "the 'new' education is in danger of taking the idea of development in altogether too formal and empty a way. The child is expected to 'develop' this or that fact or truth out of his own mind . . . without being supplied any of the environing conditions which are requisite to start and guide thought" (Dewey, 1900, p. 196).

Yet Dewey also decried a behaviorist tradition in which subject matter was broken into discipline specific areas, taught separately and each individual body of knowledge was dissected into smaller and smaller pieces to render them more understandable. Through his laboratory school Dewey and his faculty developed and promoted an educational model focused on the child and was situated in his or her community. He saw the role of a teacher as one of providing each student with an environment in which the subject matter would be a vital part of the school day and the child would be motivated to develop his or her knowledge. The teacher's role was to assist him in engaging students actively in the experience.

Dewey acknowledged differences in maturational stages of children, specifically delineating three periods. He designated adolescence as the third period, "the borderland of secondary" and suggested that "children can be brought to and through this period without sacrificing thoroughness, mental discipline, or command of technical tools of learning and with a positive enlargement of life, and a wider, freer and more open outlook upon it" (Dewey, 1900, p. 115).

Piaget (1977) described three processes as crucial to conceptual change and cognitive development: assimilation, accommodation, and equilibration. In assimilation, students deal with incoming information using their existing knowledge structures. Accommodation refers to the way that students may change their current ways of thinking to cope with new information or experiences. These two processes, assimilation and accommodation, work in concert and neither can happen without the other. Equilibration is an overarching process through which cognitive development or conceptual change take place. Equilibration happens in three phases. In the first phase, students are satisfied with their current way of thinking and are said to be in equilibrium. In the second phase, students become aware of flaws in their current thinking (disequilibrium). Finally they may adopt a more expert mode of thinking, reaching a less naïve and more stable equilibrium.

From a Piagetian perspective the learner must construct this new, more stable equilibrium as an individual, although its construction may be mediated through social interactions. For Piaget, the mechanism of learning and development is complex and developmentally constrained. In some cases, "the gifts of instruction are presented too soon or too late, or in a manner that precludes assimilation because it does not fit in with the child's spontaneous constructions" (Piaget, 1962, p. 11)

The importance of disequilibrium or conflict in the process of learning is not without controversy. Chan et al (1997) conducted a study to determine how individuals and peers dealt with information that was in conflict with their current beliefs and how that process contributed to conceptual change. They found that, although conflicting information played an important role in generating argumentative interactions, conceptual change was most effectively facilitated through subsequent knowledge-building activity (such as further consideration and explanation of conflicting information). They concluded that: "conflict in itself is not enough; it needs to be mediated by students' knowledge-building activity" (p. 35).

Vygotsky (1962) proposed a distinction between spontaneous and scientific concepts. In this view, scientific concepts are provided by the teacher and serve as a scaffold as the student builds a more systematic set of spontaneous concepts from the bottom up, eventually fitting them into the scientific concept acquired through instruction. This process may be accomplished through interaction with instructors and/or more capable peers. In "Thought and Language", Vygotsky (1962) described the process through which students might develop an understanding of concepts in science. He contended that students first become aware of 'scientific' concepts through formal instruction. In their cognitive work under the guidance of an instructor or more capable peer, they begin to integrate those formal scientific concepts with their everyday experiences ('spontaneous' concepts). In contrast to the Piagetian perspective, Vygotsky believed that instruction could drive the general process of cognitive development. In response, Piaget warned, "one must guard against an excessive bio-social optimism into which Vygotsky sometimes seems to fall" (Piaget, 1962, p. 2).

Many credit Posner and his colleagues (1982) with "the most influential theory of conceptual change in science education" (Hennessey, 2003 P. 108). In this model, conceptual change may result from the interaction between existing conceptions and new information but is dependent upon whether there is dissatisfaction with the current conception and whether the new conceptions are understandable, believable and useful. Conceptions that meet these criteria gain high status and, if they are in conflict with ideas with less status, the learner may adopt the higher status concepts.

Hatano (2003) proposed a merger between a Piagetian view and Vygotskian theories, suggesting that although "conceptual change occurs in the individual student's mind, it is induced socioculturally." (p. 408). He saw the role of the teacher as implementing comprehension activities that provide the motivation necessary to foster conceptual change. He suggested that introducing conflict (such as anomalous data) might not be enough to motivate students to do the challenging, cognitive work required to change their conceptions. This motivation, he claimed, could only arise through helping students to recognize the inadequacy of their current understanding ('cognitive incongruity') and that this incongruity could be achieved in three ways: through *surprise* (an event that contradicts prior knowledge), *perplexity* (equally plausible, but incompatible ideas), or *discoordination* (when available pieces of information are not well connected or cannot be integrated into existing models) (p. 411). Once cognitive incongruity has been achieved, Hatano maintains that students must participate in dialogical interactions with peers. Through this interactive process, students commit to an idea and are then required to explain and defend this idea to their peers. Through the process of explaining, the idea necessarily becomes more organized and any flaws in its coherence are exposed. Finally, instruction (often in the form of a confirmatory physical demonstration) ensures that the concept has been correctly understood.

Others have also proposed that social processes are essential for knowledge construction. Driver et al (1994) held the view that scientific knowledge is socially constructed and propose that discourse is a significant tool for sense making. They describe the role of the classroom teacher as having two important components: "The first is to introduce new ideas or cultural tools where necessary and to provide the support and guidance for students to make sense of these for themselves. The other is to listen and diagnose the ways in which the instructional activities are being interpreted to inform further action." This view is somewhat in concert with the Vygotskian perspective of the instructor providing the scientific concept and providing the opportunity and necessary support for the student to develop spontaneous concepts that fit within that framework.

In an opposing view, some believe conceptual change involves replacement of misconceptions. For example, Slotta et al (1995) argue that conceptual change often involves the need to revise one's understanding of a process or material substance in terms of its ontological category. They propose that students may assign concepts such as heat or force to a category of either material substance or process and that, once having done so, the rely on these classifications in making sense of physical phenomena. This gives rise to 'misconceptions' and the process of conceptual change may require a restructuring of ontological categories. The authors suggest that, in instruction: "It will be important to avoid any possible attribute matches between the instructional materials and the *material substance* category" as well as to "provide some instances of the target category" so the student may begin to build an understanding that categorizes the concept correctly.

In contrast to the avoidance approach, Wiser and Amin (2001) theorized that student conceptions (both existing and emerging) must both be acknowledged and validated to achieve conceptual change. The authors worked with four high school students over a period of five weeks, employing meta-conceptual teaching strategies to help them map across their everyday system of understanding of heat as hotness and a more scientific view of heat as exchanged energy. The intervention was divided into three parts: a free and then guided inquiry of computer models (without references to two opposing conceptualizations); meta-conceptual sessions in which the two conceptualizations were explicitly addressed; post-meta-conceptual sessions in which direct teaching was resumed. Researchers made extensive use of interviews and video- and audio-taped teaching and learning sessions.

At the beginning of the free exploration session, students saw heat energy and heat as separate entities. As students became more familiar with the models, they came to think of heat and heat energy as being concurrently emitted by the hotplate and 'traveling together' through heated objects. In the next phase, through a series of several meta-conceptual lessons, students were taught about the existence of 'two languages' (the everyday and the scientific). Careful analysis of student utterances during subsequent teaching sessions led the researchers to conclude that "this aspect (the meta-conceptual teaching) allowed students to achieve a fundamental ontological reorganization: heat, the physical entity that propagates from hotter to colder objects, and causes temperature and phase changes, comes to be understood as energy, an extensive quantity." (p. 351). They claim that, although students learned a lot about thermal phenomena in the free exploration phase, "Explicit teaching of the science view made matters worse, as it led to hypothetical conversion hypotheses between heat, energy, and heat energy" (p. 352). Until the meta-conceptual teaching occurred, students were unable to restructure their understanding.

From this brief introduction one can see that we lack a consensus with regard to what is meant by conceptual change and how conceptual change (or restructuring) may be best accomplished in science classrooms. The next section will examine, more closely, what the literature reveals about the role that verbal interactions may play in fostering the adoption of a Newtonian view.

The Role of Verbal Interaction

Can students construct a more expert understanding of physical phenomena through verbal interactions with their peers? Carey (1986) articulated a paradox related to the constructivist tradition when she said "To understand text or spoken language, one must relate it to schemata for understanding the world. But the goal of science teaching is imparting new schemata for understanding, schemata not yet in the student's repertoire. So, how is the student to understand the texts and lessons that impart new information?" (Carey, 1986, p. 1123). This section will examine studies that consider the impact that verbal interactions appear to have on learning and, finally some possible mechanisms for those effects.

The importance of dialogue is emphasized by Cazden (1988), who suggested that, as students engage in a dialogical process over time, they "take on the voice and *the authority* of scientists" (p. 3; emphasis in the original). She argued that such dialogues allow students to explore the limits of their own knowledge and take more ownership of their learning.

Chi et al (1991) found evidence that self-explanation may play a role in the development of conceptual understanding. They asked a group of ten volunteer undergraduate students to complete a pretest and a reading assignment from a physics text. They were then asked to study solved problems and complete a problem solving assignment. They were finally given a post-test. The pre- and post-tests assessed both mechanical ability and conceptual understanding of Newtonian concepts. Students were then classified as either good or poor problem solvers. Their data point to five sources of problem-solving success including: "(a) students' entering abilities, (b) their naive intuitions, (c) what they encoded from studying the text, (d) what they learned from studying the examples, and (e) what they learned from solving the problems" (p. 77). Generally, the authors found no relationship between either entering abilities or text decoding and problem solving ability. They concluded that the differing results in problem solving ability were largely due to the differential knowledge derived from studying the worked out example problems.

When students utterances during the think aloud protocols were examined, Chi et al. found that all students initially had an incomplete understanding of the principles from the text. While studying the solved problems, good problem solvers generated more self-explanations than poor problem solvers. Careful analysis of transcripts led the authors to conclude that the construction of self-explanations yielded "new general knowledge that helps complete the students' otherwise incomplete understanding of the domain principles and concepts" (p. 69). Although this research focused on solitary students, others have examined the differential success achieved through horizontal (peer-to-peer) and vertical (teacher-student) interactions.

Hatano & Inagaki (1991) suggested that *horizontal* (peer to peer) interactions are more effective than *vertical* (adult-child) interactions, reasoning that students involved in *vertical* interactions "concentrate on looking for the more capable member's desired answer, instead of figuring it out, as is often observed between a teacher and student" (Hatano & Inagaki, 1991, p. 333). In contrast, they found that students expressed their own ideas when consulting with peers, and that those ideas were more openly examined and defended, in *horizontal* interactions. In one study, fourth graders participated in a science lesson about conservation of mass when sugar was dissolved in water. Students in the experimental group participated in Hypothesis-Experiment-Instruction (HEI) protocol that included time for students to explain and discuss their choices with one another. Results demonstrated a greater depth of understanding among students who participated in the HEI protocol: "the experimental condition children could give adequate explanations about why the weight of dissolved sugar was conserved more often than could the control condition children" (Hatano & Inagaki, 1991, p. 341)

Damon (1991) argued that the best pairing (peer-to-peer or more knowledgeable other-to-peer) is dependent upon the task. He found that peer interactions were most effective when a student needed to give up a current understanding in favor of a new view, while gaining a new strategy or skill might best be accomplished by working with a more knowledgeable other. In studies of children's moral judgments children were given the task of dividing ten candy bars fairly, considering issues such as equality, gender, merit, effort and special need. They found that "56% of the children markedly increased their awareness of fairness issues . . . compared with 34% and 20% of children in control groups not exposed to *in vivo* peer discussions (the 34% group being one that was individually tutored by an adult on a similar but hypothetical set of issues" (Damon, 1991, p. 396).

Despite the many studies finding a positive impact of peer interaction on learning, the role of collaborative interaction per se has been questioned by others. Webb et al (1995) found that, although collaborative interactions are important in that they foster argumentation among peers, they may not be the only factor in promoting conceptual change. In a study involving middle school mathematics learning, findings supported the hypothesis that when a student needs help, the type of help received (explanations as compared to simply a correct answer) and the subsequent use of that help in a constructive activity are both necessary for learning. In the study, six 7th grade classes participated in two instructional units. Students in four classes worked in heterogeneous small groups throughout a three-week unit involving decimal numbers while students from all classes worked in groups through a four-week unit involving fractions.

Their analysis of transcripts of student dialogues showed that the:

> "Level of constructive activity was the strongest predictor of achievement. The level of help that students received predicted the level of constructive activity but did not predict achievement directly." (p. 406).

They distinguished constructive activity as being distinct from "time on task", describing it as "solving or explaining how to solve problems using concepts stated or implied in the explanations received" (p. 406) and concluded that "Teachers who develop a classroom culture that encourages explanations and constructive activity in peer-directed small groups will help maximize the benefits of small-group work for all group members" (p. 422).

In addition to exposing conceptual incoherence, it may be that students are more deeply engaged in thinking when they participate in peer dialogues and that this engagement leads to improved conceptual understanding. Kuhn et al (1997) employed dyadic interaction in a study meant to test the hypothesis that "engagement in thinking about a topic enhances the quality of reasoning about that topic" (p. 287). Ninety-three adolescents and young adults were randomly assigned to experimental and control groups and, through pre- and post-testing, the quality of their reasoning about the issue of capital punishment was assessed.

Analysis of transcripts attempted to explore the mechanisms in peer dialogue that supported an improved quality of reasoning. It revealed that, in less than half of the cases, a "participant adopts a form of thought modeled by a partner who holds a different position" (p. 311). In addition, the study found that "partners may ask questions that lead participants to develop their thinking further" (p. 311); partners "introduced content that served to promote participants' further development of their own arguments" (p. 312); there was "gradual evolution of a new argument during the course of dyadic discussion" (p. 312). The authors concluded: "We have, however, established dyadic interaction as a form of cognitive engagement that has effects on thinking of a positive and theoretically significant sort" (p. 314). The added: "evidence that a sustained engagement involving multiple dialogues with different partners over a period of weeks significantly enhances the quality of reasoning about a topic" (p. 307). Specifically, there was evidence of progression from one-sided to two-sided arguments, which the authors regarded as "the development of meta-cognitive awareness regarding their own and others' thinking". They attributed this development of argumentative reasoning skill to rely "entirely on peer interaction, with no guidance or introduction to new modes of thought by teachers or other adults" (p. 314).

In terms of mechanisms, Kuhn et al (1997) attempted to investigate exactly how collaborative work resulted in improved reasoning. Examination of interaction transcripts revealed that these changes were far more complex than either a conflict or cooperation model could describe. The authors found that:

> "fewer than half of the case studies examined conform to a model in which the participant adopts a form of thought modeled by a partner who holds a different position. In well over half the cases examined, new forms of argument appeared in contexts in which the partners shared the same basic position on the topic" (p. 311)

Kuhn suggested several possible processes at work. For example:

1) Partners asked questions that led participants to further develop their own thinking.

2) Partners introduced content that served to promote further development of ideas.

3) Partners pointed out the inadequacy of a statement or a faulty method of decision-making.

This study illustrated the many roles that a partner can play in the development of reasoning through collaborative dialogue.

Some studies have compared the value of peer-to-peer dialogues to those involving teachers. Hogan et al (1999) examined the discourse among groups of eighth grade students as they constructed knowledge of the nature of matter. They found that, although teacher-guided discussions tended to be a more efficient means of attaining higher quality explanations, "Overall, peer groups scored higher than teacher-guided groups on most criteria of the reasoning complexity rubric. The social structure of peer groups was more conducive to idea generation and elaboration as well as to justification of ideas. Also, the synthesis of ideas was attained more highly among peers than in teacher-guided groups." However, teacher guidance was “more essential to progression in groups that had confusion or lack of synergy among their members." (p. 425).

In an effort to foster peer-to-peer arguments in the classroom, Forman and Ansell (2002) focused on the discussion of inscriptions. In general, inscriptions could be any form of representation of an idea that permits public discussion of a concept. They might be diagrams, graphs, or any other source of information that lend themselves to the creation of an argument about those ideas. In the study, researchers utilized two sets of inscriptions: data about battery performance and data about various methods of treating patients infected with AIDS.

Their analysis of resulting conversational data revealed various specific modes of interaction. Particularly: "teachers and students were involved in revoicing each other and in listening to, reflecting on, clarifying, expanding, translating, evaluating, and integrating each other's explanations" (p. 271). It is clear, from this study, that peer interactions can take many forms, some of which could be important contributors to conceptual change.

In a longitudinal study, Hatano & Inagaki (2003) reported that the HEI method (described previously) was employed over a three-year period in elementary science classes. At the end of the three-year study, researchers asked fifth graders to write an essay describing how their ideas about molecules had changed. The essays revealed: "the term *molecules*, which was initially given as just a placeholder, was gradually enriched and became a core concept in the reorganized body of knowledge" (p. 423). These findings support the view that the role of the teacher may be to provide the scientific concept and that, through direct explorations and peer interactions, students enriched their knowledge of the concept to build a more expert view.

Although studies from PER have rarely included detailed conversational analysis, one study did attempt to investigate what patterns of conversation seemed most conducive to achieving understanding: Thornton (2004) employed a detailed analysis of undergraduate students engaged in interactive learning situations in an attempt to identify behaviors that correlate with learning. He found that students who successfully mastered physics concepts were more likely to ask open-ended questions than their non-learning peers and to offer incorrect or inconsistent explanations as they attempted to construct a more coherent understanding. Thornton also posed a question that remains to be addressed, namely, "What kinds of interactions are common and how do group dynamics affect the students in their efforts to learn?"

Stamovlasis et al (2006) set out to answer several research questions, including "How do students' benefits from cooperative learning (CL) (as demonstrated by their cognitive gains) relate to their involvement in, and contributions to, the transactions within a group?" (p. 560). The authors provided an introductory mechanics lesson to a group of 64 tenth grade students, and then administered an individual pre-test, consisting of four problem scenarios. In a second session, students were assigned to groups and completed a "group test" consisting of four similar problems that had to be completing after discussing and "negotiating" them with their groups. Finally, students were given an individual post-test, utilizing the same four problems as in the pre-test.

Among their findings, the authors noted: "statistically significant differences between spectators and active members, and between spectators and very active members. Active and very active members were not differentiated among themselves, whereas spectators did not profit from CL" (p. 570). This would indicate that active engagement in peer groups was key to achievement.

In terms of attitudes toward learning, some studies have examined students' perceptions of the value of various instructional approaches. For example, Gorsky et al (2006) investigated the study strategies employed by university students while learning physics and chemistry. Three main findings emerged from the study, including: (1) for students enrolled in large, introductory courses that were lecture based, interpersonal dialogue was largely absent and, although smaller tutorial meetings were more interactive, they accounted for only about 20% of available instructional time; (2) For students enrolled in smaller college courses, interpersonal dialogue was used significantly more often in the classroom; (3) Students in both college and university settings, when faced with a difficult problem, routinely chose to rely on each other (interpersonal dialogue) for help.

This study illustrates that class size may have an impact on the mode of instruction offered to students and, when traditional instruction fails, students turn to interpersonal dialogue as an effective learning strategy. If peer interactions are not routinely employed in classrooms, what is it about interpersonal dialogues that make them the mode of choice for learning challenging material? Perhaps they have learned, through practice, that horizontal (peer to peer) interactions are more effective in fostering knowledge construction.

Vosniadou (2003) suggested a link between interaction and intentionality: "In classrooms where science teaching is more open, follows an inquiry model, and elicits a lot of discussions and debates, students are more likely to become intentional learners capable of using a variety of sophisticated mechanisms to produce conceptual change" (Vosniadou, 2003, p. 404).

As we have seen, through a variety of mechanisms, peer-to-peer interactions have been shown to lead to improved conceptual understanding. Some theorists propose that such interactions are motivational, while others promote the importance of providing cognitive conflict to foster conceptual change. Others promote the value of the explanatory process as having an organizational effect on the explainer's knowledge. In nearly all cases, collaborative peer dialogues have played a productive role in fostering conceptual change.

Discussion

Regardless of their nature and structure, one can safely assume that a complement of persistent, naive beliefs about force and motion will pervade the thinking of novice physics students. Thus it is clear that strong conceptual change or restructuring is needed if students are to become Newtonian thinkers. Such changes cannot be accomplished without sustained, active cognitive work on the part of students. Peer interactions may be an important classroom strategy to employ in facilitating this work.

Many teachers continue to rely on traditional methods of instruction such as lecture and question and answer sessions in large group settings. This reliance on such methods may reflect the pressures of an extensive curriculum, a reluctance to lead classroom discussions, or a lack of awareness of or facility with optimal learning modes for students. A focus on inquiry methods, prominently espoused in many local and national instructional standards, may be prevalent in classrooms, but may be insufficient to engage students in a thorough consideration of how their own naive beliefs may clash with Newtonian concepts. Thus, these traditional modes of instruction are largely unsuccessful at facilitating the type of strong conceptual change or restructuring needed to develop an expert understanding of Newtonian mechanics. They may also leave students with a negative view of the field of physics and of their own ability to master such material.

Peer to peer interactions have been an important component of many successful instructional interventions in the field of Physics Research Education (PER) at the undergraduate level and may provide students with an opportunity, through discourse and argumentation, to expose inconsistencies and errors in their current thinking and to adopt a more expert understanding of concepts in mechanics. Most of the work in PER has taken place in college and university settings where it is likely that many students have already completed a formal physics course. Few have looked carefully at the nature of student interactions and how those interactions help students to construct their Newtonian view.

A few studies, mostly in different content areas have attempted to look closely at the mechanisms involved in conceptual change through peer interaction. They have suggested that the process of explaining their views to others may cause students to reorganize those views and, through that process, expose any inconsistencies or incoherence that exists in their current model. They may also provide an opportunity for integration of useful ideas and information provided by others in the group.

The cognitive gains achieved through interactive methods may be explained through a socio-constructivist theory of learning and development. The role of the instructor can be seen as providing the scientific concept and an opportunity for students to actively restructure or construct their own understanding, in conjunction with peers. They may do so by replacing incorrect pieces of their theory or by employing their own spontaneous concepts as a foundation for building a new understanding.

Physics is the most basic of the sciences and prerequisite for a thorough understanding of mechanism in many other domains. Secondary physics teachers are required to cover a broad range of topics with their students and are in need of an instructional method that is not only effective, but also efficient, and that can be readily implemented with large classes and limited resources. Peer Instruction methods, however, can possibly be integrated into an existing curriculum readily and without sacrificing a great deal of the content that is prescribed in the learning standards for the course. Studies on the effects of such methods promise to enhance our foundational knowledge of physics learning by focusing on secondary physics classrooms where students have their first serious encounter with the whole of Newtonian mechanics. Additionally, a close focus on the nature and function of student utterances, in peer conversations, and the relation of those utterances to short and long term gains in understanding may add to our knowledge of the mechanism through which such an approach may facilitate knowledge construction.

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