The Challenges of Teaching and Learning about Science in the 21st Century: Exploring the Abilities and Constraints of Adolescent Learners

Eric M. Anderman, Ph.D.

The Ohio State University

Gale M. Sinatra, Ph.D.

University of Nevada, Las Vegas

Paper Commissioned by the National Academy of Education

Please address all correspondence to: Eric M. Anderman, The Ohio State University, 165A Ramseyer Hall, 29 West Woodruff Avenue, Columbus, OH 43210, Phone: 614-688-3484 (Anderman.1@osu.edu) or Gale M. Sinatra, University of Nevada Las Vegas, 4505 Maryland Parkway, Las Vegas, NV 89154, Phone: 702-895-2605 (gale.sinatra@unlv.edu).

Abstract

In this paper, we describe the developmental status of high-school aged adolescent science learners. We specifically examine the cognitive abilities of adolescent learners across five domains: adaptability, complex communication/social skills, non-routine problem-solving skills, self-management/self-development, and systems thinking. We then describe how science educators can create social contexts that foster the emergence and development of these abilities. We conclude by providing research-based recommendations for science educators.

The Challenges of Teaching and Learning about Science in the 21st Century: Exploring the Abilities and Constraints of Adolescent Learners

The state of science education for adolescents is at an important crossroads. As the first decade of the 21st century comes to a close, we are faced with enormous scientific challenges that the youth of today will have to confront. Some of these issues include the expanding HIV/AIDS pandemic, global climate change, world hunger, space exploration, and the development and implementation of alternative sources of energy. Whereas the need for scientific advances is at its peak, adolescent learning about science in school is facing critical challenges.

Science educators in the early 21st century are facing a myriad of issues. Indeed, students in the United States still lag behind students in other nations in science achievement, particularly European and Asian countries (National Center for Education Statistics, 2007). Some of the complex issues in the field of science education include the availability of appropriate textbooks and classroom resources; the preparation and training of science teachers (including both pre-service training and in-service professional development); political and religious opposition to cutting-edge science instruction; the need to meet standards and to prepare students for standardized examinations; and the dramatically increasing use of the internet as a source of information. Given these and other issues, it is extremely important to understand, acknowledge, and build upon the abilities of adolescent learners, while at the same time tailoring instruction to address the unique challenges faced by this age group.

The field of educational psychology has much to contribute to science education. There have been many important recent developments in the study of adolescent cognition and motivation, and this new knowledge has much to add to the enhancement of science education. Learning about science requires the coordination of a complex set of cognitive, affective, and motivational strategies and skills. Specifically, research from educational psychology can contribute greatly to our understanding of how adolescents acquire and process scientific knowledge; overcome misconceptions; learn the discourse of scientists; learn to think and reason like scientists; evaluate sources of scientific information; and reconcile personal beliefs (e.g., religious and political beliefs) with science content.

In 2007, The National Research Council published *Taking Science to School: Learning and Teaching Science in Grades K-8* (National Research Council, 2007). This comprehensive report documents research-based recommendations for improving science learning for young children and early adolescents. This excellent resource covers much important information, and serves as an excellent platform from which to begin considering the unique needs of older adolescent learners.

The development that occurs in the cognitive, social, and physiological domains during adolescence is remarkable. Given these salient changes, it is important to note from the outset that adolescent science learning and instruction (i.e., particularly late middle school and high school) differs from K-8 science instruction in at least three important ways. First, adolescents' emerging cognitive abilities present unique challenges for science educators. Second, secondary science teachers usually are trained in a specific scientific discipline (e.g., a science teacher might have an undergraduate degree in biology or chemistry), compared to K-8 science teachers, who usually are trained in general teacher education programs. A third distinction is that the depth and breadth of science content for late adolescents affords the opportunity to build upon previous learning progressions through specialized electives (e.g., “Physical Anthropology” or “Biotechnology”) and enrollment in multiple science courses simultaneously. These distinctions between young science learners and adolescents afford educators the opportunity to promote greater appreciation of science as a discipline, and encourage students to consider science-related careers. These three themes serve as an overarching framework for our discussion.

In the present paper, we examine the role of educational psychology in improving science education and learning, focusing in particular on adolescents. Specifically, we examine what adolescents should be capable of doing within the following domains: adaptability, complex communication/social skills, non-routine problem-solving skills, self-management/self-development, and systems thinking. We then describe the types of educational environments and instructional practices that are needed in order to facilitate the development of abilities within these domains. Finally, we conclude with recommendations for science educators.

WHAT SHOULD ADOLESCENTS BE ABLE TO DO WITHIN EACH OF THE SIX COGNITIVE DOMAINS?

Adaptability

The current pace of change in scientific knowledge is unprecedented in human history. It took Darwin 26 years to write the *Origin of Species* to propose his theory on biological change (Mayr, 1991). In today's fast paced and constantly changing world, 26 months would be considered a long lag time for the publication of a scientific article presenting a new theory, discovery, or finding.

The fast tempo of knowledge generation in today's society requires that students be more adaptable in their thinking than ever before. The abilities and attitudes needed to adapt to the ever changing landscape of scientific ideas are myriad and varied. They include abilities, beliefs, attitudes, dispositions, goals, and motives, all of which present unique challenges for the developing adolescent learner.

The ability to think adaptively and reason about complex problems requires weighing issues and arguments and considering alternative points of views (Dole & Sinatra, 1998). Adolescents generally have the capability to reason and think critically, but this ability must be fostered and scaffolded for most students to engage with information in a critical fashion.

Even if a teacher provides the appropriate environment to support critical scientific thinking and reasoning, students often lack the requisite background knowledge to do so effectively. The ability to reason effectively and adapt to changing situations requires rich, interconnected, domain specific knowledge. Today's curricula are often characterized as a mile wide and an inch deep (Vogel, 1996). Lack of sufficient domain-specific content knowledge makes the task of thinking critically challenging if not impossible.

Beyond skills and abilities, and perhaps even more important for the adolescent learner, adaptability requires the willingness to engage in the effortful thinking necessary to consider alternative points of view. Some students are dispositionally low in "need for cognition" (Cacioppo, Petty, Feinstein, & Jarvis, 1996). That is, they do not seek out nor do they enjoy opportunities to engage in the effortful thinking required to solve complex problems.

Even if students are willing to do the "heavy lifting" required to think deeply about alternative scientific points of view, they must also be willing to have their ideas publically challenged, which can be psychologically uncomfortable for learners of all ages. Public challenges to one's point of view can be particular difficult for adolescents who are especially sensitive to the perceptions of their peer group members (e.g., Brown, 2004; Ladd, Herald-Brown, & Reiser, 2008), and may lead adolescents to develop maladaptive performance avoidance goals (Middleton & Midgley, 1997). Moreover, challenges to one's point of view can be emotionally difficult, and in some cases can even been seen as a threat to one's identity. As an example, learners who perceive their world view or religious beliefs as threatened by scientific perspectives may feel that accepting the new point of view threatens their identity. That is, they may ask themselves, "If I accept what the teacher is saying, do I have to change who I am as a person?" (Brem, Ranney, & Schindel, 2003).

Key to understanding that ideas that are the subjects of change, rather than students' personal identities is the development of an appreciation of the nature of scientific argumentation (Dushl & Osborne, 2002, Kuhn, 1993). Students differ in their willingness to engage in argumentation. Nussbaum and Bendixen (2003) demonstrated that less assertive students tend to actively avoid engaging in arguments. Other students may not see argumentation as an academic exercise because they view arguments through the lens of the more common vernacular of a conflict or an adversarial interaction involving winners and losers (Dushl & Osborne, 2002; Nussbaum & Jacobson, 2004). If adolescents, who are particularly sensitive to social discord, view arguments as disagreements, they may not appreciate the role of argumentation as a normal part of the socially constructed nature of scientific inquiry. Likewise, teachers need to appreciate the instructional benefits of argumentation and persuasive pedagogies and how to overcome the tendency of avoiding conflict when students can benefit from the right kinds of conflicts in the classroom (Sinatra & Kardash, 2004; Sinatra & Nadelson, in press).

Recognizing the need to change and the willingness to change one's thinking are hallmarks of adaptability. This requires a view of knowledge as changing and an open-minded attitude toward knowledge change. This can be a challenge for adolescents who are typically just emerging out of the absolutist stance towards knowledge (the view that there are certain and simple right answers to problems) and thus experiencing epistemic doubt (Mason, Boldrin, & Zurlo, 2006). That is, they are beginning to doubt the certainty of knowledge and tend to adopt a relativistic view that all knowledge is in doubt. This can be a dangerous perspective which can lead to a view that all opinions are equally valid and no one knowledge claim is better than any other. This presents difficulties for students' understanding that competing scientific claims must be adjudicated on the based of the superiority of the evidence.

Complex Communication Skills

Most scientific investigations are conducted by *groups* of researchers; these diverse individuals must be able to communicate clearly and efficiently. In the 21st century, more often than not interdisciplinary teams must work together to advance knowledge. Research indicates that communication skills are extremely important in the field of science. For example, proficient oral communication skills are related to candidates' scores on medical specialty certification examinations (Houston & Smith, 2008). From a Vygotskian perspective, if more sophisticated learners are going to lure their peers into their respective zones of proximal development and thus enhance cognitive growth in scientific thinking, effective communication is necessary (cf. Vygotsky, 1978).

Adolescents have the capability to communicate effectively about abstract concepts. From a Piagetian perspective, most high school students are operating at a level of formal operational thought, where they can understand complex and abstract phenomena (Inhelder & Piaget, 2008). However, adolescents may not be able to communicate this information to each other and to external audiences effectively. In addition, the extraordinarily important role of peers in the lives of adolescents is conducive to cooperative group assignments in which adolescents work together and communicate scientific information to each other and to others.

Nevertheless, most important is the adolescent’s ability to learn to communicate effectively about science. It is important to note that communication occurs in several different ways: via written communication, and via oral communication.

Written communication. There are numerous theoretical models that explain the development of writing skills in learners (e.g., Bereiter & Scarmadalia, 1987; Hayes, 1996; Hayes & Flower, 1980; Zimmerman & Risemberg, 1997). In a review of the literature on the development of writing skills, Graham (2006) notes that writing is a complex process. Good writers need to learn and master several different skills and strategies; for example, they need to learn self-regulatory skills (e.g., the ability to plan writing beforehand, and revise writing afterward), and skills that are specific to the actual writing process (e.g., complex sentence construction, writing within the genre of science). In addition, effective writers need to have knowledge about writing (e.g., the intended audience, information about the topic, etc.), and effective writers need to be motivated to write (i.e., they need to feel self-efficacious) (Pajares, 2003).

Research on writing indicates that effective writing skills can be taught to adolescents. We note that training in this area for science educators is lacking; if adolescents are going to become well prepared for entry into science-related careers, science educators need to be trained in how to instruct their students in scientific writing. Specifically, science educators need to incorporate specific principles of writing instruction into science lessons. These principles include teaching specific strategies and skills, structuring the environment to be conducive to writing, and encouraging students to learn to write in collaboration with peers (Graham, 2006).

Oral communication. Adolescents have the cognitive abilities to understand complex scientific phenomena; however, the ability to orally discuss and report on these phenomena may not reflect the cognitive capabilities of adolescents. Indeed, little formal curricula in high schools address communication skills in adolescent populations.

Science educators can incorporate techniques into their instruction that facilitate the development of oral communication skills about science. One of the most readily available and useful cooperative learning techniques is referred to in the literature as *Jigsaw* (Slavin, 1995). In Jigsaw, every member of a group is responsible for becoming an “expert” in a particular area. That expert then reports back and teaches the other members of the group about the specific topic. In this manner, students scaffold and support each other's communication, so that the "expert" learns to effectively communicate to the group members, so that they can learn the necessary information.

Non-Routine Problem Solving Skills

Scientific problems of import require non-routine problem solving. That is, most problems worth solving are ill-structured and required "thinking outside the box" for an effective solution strategy. In general, successful problem solving requires domain-specific knowledge and skills (Chi & Glaser, 1985) and the procedural and conditional knowledge to know when and how to apply those skills (Paris, Lipson, & Wixson, 1983). Non-routine problem solving requires the ability to metacognitively monitor and self-regulate relevant skills and strategies. In addition, effective problem solvers also need the "will" (the motivational goals, attitudes, and interests) to attend to the problem and persist in the face of difficulties (Mayer, 1998; Paris et al., 1983).

Many adolescents have the reasoning, metacognitive, and self-regulatory skills necessary for problem solving, but the motivation to approach difficult problems and persist toward solutions is rare among individuals of all ages. Fortunately, studies of problem solving skills and creativity have been vibrant areas of research for decades, and much is known about how to support these skills (Mayer, 1998; Sternberg, 1999). Less is known about promoting interest and willingness to persist on non-routine problem solving, but advances in this area are accumulating. Mayer points out the importance of the motivational factors of interest, self-efficacy, and attributions (Mayer, 1998). Students tend to engage more deeply and persist on challenging problems if they find them interesting. Simply connecting a problem to students' lives can be effective in promoting interest (Anand & Ross, 1987). Students are more likely to persist in pursuit of problem solutions if they feel efficacious, that is, if they judge themselves as capable of solving the problem (Schunk & Zimmerman, 2006). Self-efficacy can be promoted by encouragement, but is best promoted by actual problem solving success. Mayer argues the key to successful problem solving is linking the skills, strategies, and motivation in service of the same outcome.

Sternberg notes that creativity, which can lead to new scientific discoveries, involves intellectual abilities, knowledge, and motivation, as does problem solving. But, he posits that creativity also requires the disposition or preference for engaging in novel ways of thinking (Sternberg, 1999). He characterizes these dispositions as “thinking styles” (Sternberg, 1997). Thinking styles describes individual differences not in abilities, but in preferences for the use of our abilities. He claims that matching learners’ thinking styles to their learning environment can enhance creative thinking and problem solving. He has demonstrated through a number of summer programs with high school student that creativity can be fostered using his approach (Sternberg, 2006).

In their examination of the reasoning skills required of adolescents to engage in classroom inquiry, Chinn and Malhota (2002) cautioned that overly simplistic forms of inquiry do not promote the reasoning skills scientists engage in during authentic inquiry. Their detailed analysis illustrates that too few of the cognitive processes required by scientists’ reasoning during inquiry (such as planning, systematic control of variables, and constructing explanations of results) are required of school based inquiry tasks. The result is that students engage in algorithmic reasoning, not the high level reasoning required to think about alternative explanations or to connect theory to data. Ultimately, students engaged in overly simplistic inquiry tasks may not develop the reasoning skills necessary to solve non-routine problems, or worse, may not develop an appreciation of the complexity of science itself. Chinn and Malhota (2002) make recommendations to improve inquiry pedagogy by incorporating more of the processes and procedures of authentic scientific inquiry into implementations of classroom inquiry.

Self-Management/Self-Development

There are a variety of terms that describe students' abilities to manage and regulate their behaviors. Self-regulation is probably the most commonly used term; self-regulation refers to the ability of students to control, regulate, and monitor their use of various learning strategies (e.g., Zimmerman, 2000). Self-regulated learners set goals for their learning, and then monitor their progress and adjust their strategies toward reaching those goals. Related to self-regulation is metacognition, which is the ability to think about one's own thinking (Meichenbaum, Burland, Gruson, & Cameron, 1985). Research indicates that adolescents are capable of engaging in self-regulatory strategies, and that instruction can be tailored to enhance self-regulation.

There are several contemporary models of self-regulation which can be applied to science learning in adolescent populations. Pintrich (2000) elaborated on four phases of self-regulation: (a) forethought, planning, and activation, (b) monitoring, (c) control, and (d) reaction and reflection. In a separate but related model, Zimmerman (2000, 2001) argues that self-regulation is comprised of (a) forethought, (b) performance/volitional control, and (c) self-reflection; these three processes operate in a cyclical manner, with the processes recurring again and again. Both Zimmerman’s model and Pintrich’s model include self-efficacy as a critical component in the self-regulatory process; specifically, individuals can only engage in the various self-regulatory phases (e.g., self-reflection) if they feel efficacious in that domain (Schunk & Zimmerman, 2006).

Research indicates that self-regulatory skills are extremely important in the domain of science. In a study of adolescents' use of self-regulatory processes while learning about the circulatory system using hypermedia, Greene and Azevedo (2007) found that the use of self-regulatory processes was related to conceptual change in learners; students who engaged in more effective self-regulation developed a more advanced understanding of the complex topics being studied. A large-scale study of Turkish adolescents indicated that students with good self-regulatory skills (e.g., controlled use of organizational skills; management of study environment) had higher achievement in biology (Yumusak, Sungur, & Cakiroglu, 2007).

Science educators can support the development of self-regulation in their students in several ways. First and foremost, students must be allowed to have some control over how they learn or process science material. Self-regulation is by definition a "self" controlled process; when science curricula are tightly regulated and prescribed by the teacher (offering students little flexibility) students are unlikely to engage in self-regulatory behaviors (Pintrich, 2000). Second, educators must encourage students to evaluate their work as they progress (Pintrich & Schunk, 2002; Schunk & Ertmer, 1999). If students do not stop and reflect on whether they are reaching their goals, then they often will not attain their goals, particularly if they do not adjust their strategies when necessary.

Systems Thinking

Today's world is a complex place and scientific problems increasingly require abstract reasoning about systems to appreciate their intricacies (Goldstone & Sakamoto, 2003). Consider problems such as tornado forecasting, predicting the catastrophic effects of a pandemic, or understanding the reasons for the decline in the bee population: understanding each of these requires students to be able to think about how multiple systems interact. Complex systems have multiple component parts and processes that interact in ways that that give rise to emergent phenomena (Chi, 2005). That is, the resulting phenomena are the result of the agents in the system self-organizing in ways that often cannot easily be inferred from their individual actions. Consider the V pattern that emerges from birds in flight. This pattern is the result of each bird seeking the path of the least resistance and is not predictable from examining the flight mechanics of individual birds, but rather can only be understood from examining their individual actions in interaction (Chi, 2005). Unfortunately, despite the need for systems thinking, research is beginning to show how difficult it is for students to appreciate emergent systems even with specific directed instruction (Chi, 2005; Slotta & Chi, 2006).

Despite the challenges of teaching and learning about complex systems, adolescents are capable of the level of abstract thought necessary to grasp these complexities. Furthermore, it is worth the effort to promote systems thinking because the underlying scientific principles are applicable to multiple domains (Goldstone & Sakamoto, 2003). A promising approach for developing students' appreciation of the complex and abstract nature of systems is the use of computer simulations (Jackson, Stratford, Krajcik, & Soloway, 1996) that assist students in constructing the appropriate mental models from which they can think and reason about these systems (Gentner & Stevens, 1983). There are many difficulties yet to understand and overcome before computer simulations are maximally effective, however, the increasingly wide spread use of computers in classrooms are making these approaches more accessible to students and teachers presenting promising avenues for future research.

CREATING SCIENCE CLASSROOMS THAT SUPPORT THE EMERGENCE OF ADOLESCENTS' COGNITIVE ABILITIES

Much research in recent years has indicated that science classrooms can be created in ways that enhance the cognitive abilities of adolescents. Teachers can have profound effects on adolescents' cognition and motivation as they attend to daily, routine issues. The specific decisions that science teachers make on a daily basis can affect a number of important educational outcomes.

The types of instructional practices that teachers use affect how students learn in important ways. Teachers make choices everyday regarding (a) the types of tasks that they will use in class and for homework assignments; (b) the types of rewards that students can earn; (c) assessment procedures; (d) grouping arrangements (e.g., heterogeneous vs. homogeneous); (e) how much autonomy will be afforded to students; and (f) whether or not they will hold high expectations for all students (Anderman & Anderman, 2009). The decisions that teachers make about each of these instructional practices are related in important ways to how well students learn science, to students' motivation toward science (including their desire to study science in the future), and their beliefs about their own abilities in science.

In the following sections, we elaborate on three domains of science instruction in which research clearly indicates how science educators can tailor instructional environments to yield maximum engagement, conceptual change, and knowledge acquisition for adolescents. If we want adolescents to consider science-related careers, and if we want to reduce gender gaps in science achievement and in participation in science, then providing more effective instructional environments for adolescent science students is of paramount importance (Eccles, 1984; Eccles, 1994).

Creating Adaptive Motivational Contexts in Science Classrooms

There has been much research in recent years examining the role of motivational constructs in science education. In particular, research clearly indicates that the types of motivational goals, beliefs, and attitudes that students have are directly related to the ways in which students cognitively process information.

Research from a goal orientation theory perspective explains the complex relations between the motivational climates created by teachers in classrooms, and students' cognitive functioning (Ames, 1992; Dweck & Leggett, 1988; Nicholls, 1989; Pintrich, 2000). In 1990, Nolen and Haladyna (1990) demonstrated that in high school science classrooms, students' beliefs in the usefulness of deep cognitive processing strategies (e.g., monitoring of comprehension, relating new information to prior knowledge, organizing newly learned information) was related to a task (mastery) orientation (i.e., feeling successful when learning new information) (Nolen & Haladyna, 1990). In a related study, Anderman and Young (1994) used multilevel modeling (HLM) to examine the relations between teachers' instructional practices in adolescent science classrooms and student outcomes. Results indicated that teachers' use of ability-focused instructional practices (e.g., displaying the work of the highest achieving students as examples, pointing out students who do exceptionally well in science, giving special privileges to students who do well in science) was related to lower levels of mastery goal orientation in their students. Results also indicated that holding mastery goals in science was correlated positively with the use of deep-level cognitive processing strategies, whereas holding performance goals (i.e., focusing on grades or on doing easy work) was correlated positively with the use of surface-level cognitive strategies (e.g., memorizing facts) (Anderman & Young, 1994).

These findings are important because research indicates that the types of personal goals (e.g., mastery or performance goals) that students adopt are context-specific, and are largely determined by the choices that teachers make about the types of instructional practices that they will use (Roeser, Midgley, & Urdan, 1996), particularly for adolescents (Anderman & Maehr, 1994). Specifically, when science teachers use discourse that focuses on mastery, improvement, effort, and the inherent value of science, students are likely to adopt mastery goals; in contrast, when teachers consistently talk about relative ability, grades, extrinsic outcomes, and test scores, students are likely to adopt performance goals (Maehr & Midgley, 1996; Midgley, Kaplan, & Middleton, 2001).

Research from an expectancy-value perspective also explains how classroom level practices affect motivational beliefs which ultimately affect important choices (e.g., career-related decisions). Eccles and her colleagues have demonstrated that whereas expectancies are related to achievement (i.e., grades), achievement *values* are related to the choices that students make (Wigfield & Eccles, 1992). Specifically, students who report high achievement values toward science feel that science is (a) useful, (b) interesting, (c) important, and (d) worth their time (Eccles et al., 1983). When students hold these positive beliefs about science, they are more likely to choose to take science courses when those courses become electives, and ultimately to choose science-related careers in the future (Wigfield & Eccles, 1992).

Research also indicates that teachers' selection of instructional practices is related to the development of achievement values. For example, results from a longitudinal study indicate that when teachers use performance-oriented instructional strategies during instruction (e.g., emphasizing the importance of high grades; emphasizing who in class is doing the "best" at their work), students' achievement values in mathematics decline over the course of an academic year (Anderman et al., 2001).

In summary, teachers create motivational contexts in their classrooms via the choices that they make on a daily basis about instruction. The discourse and practices that teachers use in adolescent science classrooms are related to the types of goals and values that students adopt. These goal and values, in turn, are related both to academic achievement, and to choices (e.g., career choices) later in life. Thus small decisions made on a daily basis can be related in profound ways to student outcomes in science.

Assessment Practices

The types of assessment practices that science teachers employ are also related to the types of cognitive skills that adolescents use in classrooms. Given the current national focus on standards and the *No Child Left Behind* (NCLB) legislation, it isn't surprising that educators are more cognizant than ever about assessment of student learning. This legislation has had profound effects on how learning occurs in classrooms. Berliner and his colleagues (e.g., Nichols and Berliner, 2007) have argued that the high-stakes testing that is required as part of NCLB is detrimental to education in many ways.

The cognitive strategies and motivational beliefs that students employ are largely determined by how they are assessed (Paris, Lawton, & Turner, 1992). When exams focus on memorizing facts and direct recall of factual information, students are unlikely to engage in higher-order cognitive strategy use, and conceptual change is unlikely to occur; in contrast, when assessments are focused on solving real-world problems, and build upon prior knowledge, students are more likely to engage in higher-order thinking, to use deep cognitive processing strategies, to think creatively, and to experience conceptual change (Dole & Sinatra, 1998).

In addition, assessment practices in science also reflect the motivational contexts that educators create in science classrooms. Research indicates that in science classrooms, a focus on extrinsic outcomes (e.g., talking about test scores and grades) is associated with increased cheating in science classrooms (Anderman, Griessinger, & Westerfield, 1998). Blumenfeld and colleagues' project-based learning serves as an excellent example of a method of instruction that drives the development and usage of high-order cognitive strategies within a highly motivational academic task. Blumenfeld and her colleagues note that traditional assessments, which often focus on basic comprehension of science material, may be inappropriate in project-based learning; rather, educators need to assess student learning in different ways, particularly in order to understand what students actually know before engaging with the project (Blumenfeld et al., 1991). These researchers have made excellent use of technology as a means of delivering and assessing learning in project-based science projects.

In summary, the types of assessments that students are given in science education affects the cognitive abilities that students will apply when studying science. If exams call for mere regurgitation of facts, then students are unlikely to engage in conceptual thinking and higher-order problem solving; in contrast, if assessments focus on being able to solve real-world problems then students are more likely to engage in complex cognitive processes during science instruction.

Classroom Social Environment

As aforementioned, teachers' choices of instructional practices greatly affect the motivational contexts of science classrooms. However, another area of research that is starting to receive much needed attention is the study of *classroom social environments*. Both interactions between peers, as well as interactions between students and teachers, are related in important ways to students' cognitive engagement with and learning from their academic work.

Research indicates that teachers make choices about whether or not they will pursue interpersonal relationships with their students (Davis, 2003; Davis, Ashley, & Couch, 2003) . Specifically, when teachers are committed to having positive interpersonal relationships with their students, academic achievement is enhanced (Delpit, 1995, Reeve, in press). There are several theoretical explanations for why the relationships between teachers and students facilitate learning.

Self-determination theory offers one perspective on this issue. Deci and Ryan (1985) note that individuals have three basic needs: the needs for competence, autonomy, and relatedness. The "relatedness" need in particular focuses on the need to have positive interpersonal relationships with other humans. For adolescents in particular, the need for relatedness (with both peers and teachers) is particularly important, given the salient role of peers in adolescents' lives (Brown, 2004). When these three needs are met, individuals will internalize behaviors and beliefs that initially were external to the individual. In terms of science education, when science teachers nurture interpersonal relationships between students and themselves, students' relatedness needs will be met; consequently, students will be more likely to internalize some of the norms and behaviors (related to the practice of science) that are being taught in the classroom (Deci & Ryan, 1985; Deci & Ryan, 1994).

In addition, research on school belonging also has received much attention in recent years. Although school belonging (i.e., perceiving a sense of safety, comfort, and being welcomed in schools and in classrooms) has been demonstrated to be related to lesser engagement in risky behaviors during adolescence (Resnick et al., 1997), more recent research indicates that school belonging is related to beneficial learning outcomes for adolescents (e.g., greater achievement and cognitive engagement) (Anderman, 2002). Studies indicate that school staff can promote belonging in both classrooms and schools through various reform efforts (Battistich, Solomon, Watson, & Schaps, 1997).

RECOMMENDATIONS FOR SCIENCE EDUCATORS

From our perspective, there are number of constructive, affordable, and practical recommendations that emerge from an educational psychology perspective on adolescent learning in the sciences. Specifically, we make the following seven recommendations which we list, then describe below:

1. *Foster productive learning environments.*
2. *Promote active engagement based on connections to students' personal interests and career goals.*

3. *Develop requisite knowledge, skills, and dispositions necessary for science literacy and to support nascent science career choices.*
4. *Capitalize on learning progressions by revisiting earlier content in more depth.*
5. *Promote an inquiry and problem-based learning approach to science instruction.*
6. *Use assessments that focus on higher-order learning.*
7. *Provide professional development for secondary science in-service and pre-service teachers that includes adolescent development and motivation.*

Recommendation #1: Foster Productive Learning Environments

Teachers should strive to create contexts conducive to science learning in their classrooms. We recommend an environment that is actively engaging, flexible, social and cooperative, and that promotes independent inquiry and problem-based learning (PBL).

Adolescents are more likely to be engaged when they are actively working in cooperative, social groups, with flexibility of choice both of topics to study and roles to play. Teachers should capitalize on students' desires to be with their peer group members and adopt investigative teams, lab groups, and cooperative learning approaches to learning. Grouping must be structured with care to promote positive and productive interactions (Slavin, 1995; Slavin & Cooper, 1999).

Recommendation #2: Promote active engagement based on connections to students' personal interests and goals.

Adolescents are just developing what can become lifelong interests and passions and may be in the later phase of interest development or what Hidi and Renninger call "well developed individual interest" (Hidi & Renninger, 2006). Students are much more likely to be actively engaged when teachers allow them the flexibility to work in groups and explore topics of their own choosing that capitalize on their emerging interests (Hidi, Weiss, Berndorff, & Nolen, 1998).

At the same time, adolescence is typically characterized as a critical time of identity formation where through questioning and exploration individuals come to achieve a sense of who they are as a person or a “sense of self” (Marcia, 1966, 1980). Recently, Renninger has suggested that teachers can capitalize on students’ phase of interest development and their identity development simultaneously to promote the development of deep interest that leads to meaningful learning (Renninger, in press). Related to individual interests, individuals are much more likely to engage deeply with content they find personally relevant (Fredricks, Blumenfeld, & Paris, 2004). In adolescents, these conditions intersect with their budding career aspirations, creating the opportunity to capitalize on this “perfect storm” of intersecting interests, identity development, personal relevance and career aspirations. This provides a unique opportunity to create the conditions necessary for sustained engagement and individual interest development that can lead students to choose science as a career.

At the same time, these conditions cast minority and female students in particular in a precarious position where negative experiences can lead to a decision to permanently leave science behind for other interests. Misconceptions about the nature of science and scientists’ work can lead young girls to comment as this one eight grader did in a recent study: “I want to work with people, not become a scientist” (Renninger, in press, p. 3). Therefore, particularly attention must be paid to promoting an environment where women and minorities see themselves as potential scientists and have realistic ideas about opportunities for their future in the sciences (Eccles, 1994).

In addition, the possibility of internships in which students are afforded opportunities to engage in real scientific practices under the supervision of professional scientists provides a unique opportunity for adolescents. Research from evaluations of undergraduate research experiences (UREs) has demonstrated their effectiveness in building students appreciation for both the content and process of science (Kardash, 2000). Apprenticeship learning has been shown to be effective with adolescents as young as middle schoolers when properly structured to support "doing authentic science 'at the elbows' of real scientists (Barab & Hay, 2001, p. 98).

Recommendation #3: Develop requisite knowledge, skills, and dispositions.

Sufficient content knowledge is necessary to reason and think critically. Today's students can be thought of as members of the "Google Generation." That is, they have grown up in era where a vast amount of information is just a few key strokes away and available in an instant. Adolescents' attitudes towards content knowledge now more than ever before can be reflected by the question "why do I need to know this, I can just Google it." Therefore, building background knowledge and providing a rationale for that knowledge is more critical than ever. According to Alexander's Model of Domain Learning (Alexander, Jetton, & Kulikowich, 1995), students need to move toward the proficiency stage of knowledge development before they have sufficient knowledge with which to reason critically. Therefore, teachers must determine the level of their students' background knowledge, as well as identify misconceptions and alternative conceptions before each new topic is broached.

A host of knowledge building techniques can assist teachers in their efforts to shore up students' requisite background knowledge. Collaborative environments such as Knowledge Forum (Scardamalia & Bereiter, 1991; 1993) capitalize on the preference of adolescents to work in socially engaging environments. The goal is for classroom structures to promote a knowledge-centered environment designed to develop understanding and facilitate knowledge transfer (NRC, 2000).

When misconceptions and alternative conceptions are present, there are a host of effective research-based conceptual change approaches that can be integrated into science instruction, (for an overview see Duit, Treagust, and Widodo, 2008). These approaches include the use of refutational texts (Guzzetti, Snyder, Glass, & Gamas, (1993), modeling (Jonassen, 2008), promoting cognitive conflict (Chan, Burtis, & Bereiter, 1997), collaborative argumentation (Nussbaum & Sinatra, 2003), persuasive pedagogies (Sinatra & Kardash, 2005), and self explanation (Chi, 2000), just to name a few.

At the same time, students may need to be taught the self-regulations skill (Schunk & Zimmerman, 2008) and the learning strategies characteristic of the proficient learner (Alexander et al., 1995). Particularly important is the development of students' understanding of the nature of science (Lederman, 2007), their personal epistemologies (their beliefs about the nature of knowledge and knowing) (Hofer & Pintrich, 1997) as well as their attitudes and dispositions towards knowledge (Stanovich, 1999). Research has shown developmental differences in epistemic beliefs with adolescents developing a more evaluativist stance toward understanding the physical world in eighth grade, but a disturbing trend toward more absolutist views of science in later grades (Mason et al., 2006), suggesting a need for continued emphasis on scientific knowledge as constantly evolving.

Dispositions, such as actively open-minded thinking (Sá, Kelley, & Stanovich, 2005), and need for cognition (Cacioppo et al., 1996), are individual differences that are more or less stable but can be fostered towards a greater degree of appreciation for nuanced and complex issues. Appreciation of the complex nature of science, along with development of more scientific beliefs, attitudes, and dispositions toward knowledge, provide a foundation for understanding the scientific enterprise. These characteristics, along with an appreciation for scientific argumentation (Duschl & Osborne 2002), can lead to improvement in students' abilities to adjudicate conflicting knowledge claims and to evaluate scientific evidence (Nussbaum, Sinatra, & Poliquinn, 2008).

These are also skills necessary for the critical evaluation of web-based information. Previously the work of textbook publishing companies or journal editors, the task of evaluating the credibility and reliability of scientific information obtained over the web now falls on the student (Bråten, & Strømsø, 2006). Students need to distinquish fact from opinion, trustworthy from untrustworthy websites, as well as recognize bias, proganda, and comericial information (Mason & Boldrin, 2008). It has been demonstrated that students do not reliably question the validity of information obtained via the internet without guidance (Kuiper, Volman, & Terwel, 2005). Mason and Boldrin (2008) demonstrated that middle schoolers were unable to reliably identify conflicting information on the web and were less able to evaluate the credibility of websites than were high school students. Key factors in high schoolers' greater abilities to judge web-based information were degree of background knowledge and more sophisticated epistemic beliefs (Mason, Boldrin, & Ariasi, in press).

Recommendation # 4: Capitalize on learning progressions by revisiting earlier content in more depth.

As noted in our introduction, science instruction in the secondary environment offers unique opportunities to capitalize on not only the growing capabilities of adolescent students, but their teachers' greater specialized expertise. Secondary teachers are trained in science as a discipline. They tend to have undergraduate degrees in discipline specific domains such as chemistry, biology, and physics. Their content knowledge allows them to model thinking and acting like a scientist in their discipline and affords an opportunity for supporting students in domain-specific inquiry.

The depth and breadth of the content in secondary science classrooms enhances science teachers' opportunities to build on previous topics touched on in earlier learning progressions. In particular, higher order thinking and conceptual change will be promoted in adolescent science classrooms if teachers do not treat each science course as a mutually exclusive, discrete class; rather, teachers must work more collaboratively so that information learned in one science class is reviewed and reinforced in subsequent classes. For example, cognitive growth could be enhanced as chemistry and biology teachers work more closely to demonstrate to students how these two scientific disciplines are intricately related (e.g., in the field of biochemistry). Students in high schools often have the opportunity to take specialized electives such as physical anthropology, and they often can take multiple science courses simultaneously. This affords the opportunity to promote greater appreciation of science as a discipline and should foster growth in the consideration of science-related careers.

Recommendation #5: Promote an inquiry and problem-based learning approach to science instruction.

Research in inquiry (Chinn & Malhotra, 2002; Duschl & Grandy, 2008) and problem based learning (Hemlo-Silver, 2004) has demonstrated the efficacy of these approaches when students' level of background knowledge and their skill sets are taken into account and appropriate learning scaffolds are provided (Nadelson, in press; Sandoval & Reiser, 2004). Though not without their challenges (Chinn & Malhotra, 2002, Kirschner, et al., 2006, Settlage, 2007) these approaches have the potential to be effective in secondary education due to both the greater cognitive capabilities of the students and the greater content expertise of their teachers.

So much has been written on inquiry that little needs to be reiterated about the method and its challenges and potential benefits (see for example, Abd-El-Khalick, et al. 2004; Duschl & Grandy, 2008). Science education reform efforts have focused on inquiry for the purpose of understanding both the process and nature of science, as well as the learning of science content (AAAS, 1993, NRC, 1996). Indeed, Anderson has called inquiry the "organizing theme for science curricula" (Anderson, 2007, p. 807). Despite the abundance of research, reform efforts, and calls for inquiry instruction to promote understanding of science content and process, little has been focused on capitalizing on the developing capabilities of the adolescent to think and reason critically and to regulate their learning to bolster the potential for effective inquiry curricula.

In problem-based learning (or PBL), an approach originally developed in medical schools, students work in collaborative groups to explore meaningful problems while the teacher guides students through a learning cycle that overlaps significantly with the methods and learning goals of inquiry (for example students identify known facts, generate hypotheses, and self direct their learning) (Hemlo-Silver, 2004). The process requires significant use of self-regulated learning skills and metacognitive strategies; the use of these strategies facilitates the effectiveness of PBL with adolescent science learners. The success of both of these instructional methods requires a skillful and knowledgeable teacher and the need for high quality professional development (see recommendation #7).

Recommendation #6: Use assessments that focus on higher-order learning.

The assessment of science learning has multiple objectives. Science teachers construct assessments for classroom use to determine what their students know prior to instruction (formative assessment) and what they have learned from instruction (summative assessment) (Bell, 2007). In addition, assessments form the basis of meeting accountability requirements such as score reporting to outside agencies, program accreditation, program evaluation, and national and international comparisons.

Our recommendations for classroom assessment include encouraging a change in focus toward assessment models and techniques that promote, rather than simply measure, science learning. We encourage a greater role for formative assessment, a focus on assessments that require higher levels of critical thinking and reasoning, group-based assessments, and a move away from the extrinsic emphasis on grades.

Knowing what students know prior to instruction is particularly important in science classrooms. We know that students come to the learning situation with ideas of their own, many of which are in conflict with science content. Prior topic knowledge assessments often are used in science classrooms. However, we would recommend a greater emphasis be placed on formative assessment to better inform teachers about how to tailor their instruction to build requisite prior knowledge and address misconceptions. We recommend not only assessing prior knowledge, but incorporating assessment of prior beliefs, such as beliefs about the nature of science and epistemic beliefs (beliefs about the nature of knowledge) into formative assessments. Since both nature of science beliefs and epistemic beliefs affect learning about science content, we recommend that teachers incorporate measures of these belief systems prior to instruction. In addition, understanding students learning dispositions or thinking styles (that is students attitudes towards science) helps to frame science instruction. Learning dispositions can be measured quickly and effectively with Likert scale surveys (Sa et al., 2005).

Next, we recommend that classroom assessment be focused away from examinations designed to determine factual knowledge and toward assessments that require higher order thinking, reasoning, and problem solving (Treagust, Jacobowitz, Gallagher, & Parker, 2001). The use of performance assessments, such as concept mapping, portfolios, dynamic assessments, interviews, and computer-based assessments are certainly on the rise (Bell, 2007). We encourage a continuation of this trend toward assessments that require critical thinking in the science classroom.

Since we recommend inquiry and PBL activities, which are often done in groups, more focus must be placed on group grading systems that are fair and systematic. Many strategies for group grading are available, such as giving the same grade to each group member (Lowe & Fischer, 2000), or giving two grades, one for the group's effort and one for the individual's contribution, or a combined method of weighting group and individual contributions. Group grading can encourage the type of cooperation required by research teams.

Our last recommendation for classroom assessment is for a refocus away from the extrinsic grade race, which has been shown to undermine students' intrinsic motivation and promote cheating (Anderman et al., 1998) and to move towards assessments that promote mastery of content (Blumenfeld et al., 1991).

The other main purpose of assessment is accountability. The focus on accountability and large-scale assessments has increased under NCLB (Britton & Schneider, 2007). Britton and Schneider (2007) note that the increased emphasis on large-scale assessments presents both a challenge and a risk to science education in that high-stakes assessments can increase the amount of time spent on science instruction, but these assessments may not promote science learning for all children. They caution "there is a danger of assessment pushing teaching and learning in undesired directions that are counterproductive to the goals of scientific literacy" (p. 1009).

Recommendation #7: Professional development for secondary science in-service and pre-service teachers should include adolescent development and motivation.

Professional development of secondary teachers should include courses and modules in adolescent development and motivation. Teacher education programs often do not well prepare secondary education students in the developmental and psychological issues that are so important in understanding how adolescents learn (Patrick, L.

Anderman, Breuning, & Duffin, 2009). Much research suggests that there are both effective and ineffective ways to provide professional development for teachers. A large-scale study of the effectiveness of professional development programs with a nationally representative sample of science and math teachers indicates that effective professional development programs (i.e., programs that promote change in teachers' behaviors) should be intensive (i.e., not short-term "drive by" sessions), should focus on specific academic content, should give teachers the opportunity to actively engage with tasks (i.e., hands-on learning), and should be integrated into the school's overall practices and culture (Garet, Porter, Desimone, Birman, & Yoon, 2001).

However, we contend that it also is extremely important to include professional development activities that foster growth in teachers' understanding of how adolescents learn. There have been various calls for the need to provide professional development that enhances teachers' understanding of how students learn (e.g., Darling-Hammond & McLaughlin, 1995). Teachers' beliefs about how students learn, as well as teachers' own epistemic beliefs about knowledge, influence the types of instructional practices that they use in classrooms (Maggioni & Parkinson, 2008); consequently, in order to ensure that science teachers choose appropriate instructional practices during daily instruction, school leaders have a responsibility to include instruction regarding adolescent learning, cognition, and motivation in professional development activities.

The most useful types of professional development for science teachers will be programs that integrate information about adolescent learning and development with science content. Thus by utilizing the extant research on effective professional development, we suggest that effective programs will be enduring (i.e., not short-term), and will allow teachers to actively integrate knowledge about how adolescents learn with actual science curricular content.

CONCLUSION

In this paper, we have argued that adolescents have extraordinary cognitive abilities, and that these cognitive abilities need to be acknowledged and understood by science educators. We have attempted to integrate research from different domains of educational psychology, to demonstrate that science education can be tailored to the needs of adolescents.

Science educators must understand developmental processes. High school science teachers need to understand not only how their students learn, they need to understand where their students came from (i.e., typical cognitive development of middle grade students), and where they are going (i.e., continued cognitive development during early adulthood). We contend that it is the intersection of teachers' knowledge about adolescent cognition and teachers' knowledge about creating effective classroom environments that will lead to enhanced scientific learning for adolescents.

Most important, we are at a critical point in terms of encouraging adolescents to consider careers in science. Many American jobs are being shipped overseas to highly qualified individuals who are well trained in science. Many American students turn away from science-related disciplines because they have had bad experiences in science classes during high school. Young women and minorities are under-represented in science careers in the academy and in business and industry. We strongly argue that many of negative experiences associated with the learning of science in schools can be avoided if science educators are cognizant of both the cognitive abilities of all adolescent learners, and the types of learning environments that are most conducive to fostering the use of these abilities.

References

American Association for the Advancement of Science (AAAS). (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

Abd-El-Khalick, F., Boujaoude, S., Duschl, R., Lederman, N. G., Mamlok-Naaman, R., & Hofstein, A. et al. (2004). Inquiry in science education: International perspectives. *Science Education, 88*(3), 397-419.

Alexander, P. A., Jetton, T. L., & Kulikowich, J. M. (1995). Interrelationship of knowledge, interest, and recall: Assessing a model of domain learning. *Journal of Educational Psychology, 87*, 559-575.

Ames, C. (1992). Classrooms: Goals, structures, and student motivation. *Journal of Educational Psychology, 84*(3), 261-271.

Anand, P.G.&Ross, S.M. (1987). Using computer-assisted instruction to personalize arithmetic materials for elementary school children. *Journal of Educational Psychology 79*, 72–78.

Anderman, E. M. (2002). School effects on psychological outcomes during adolescence. *Journal of Educational Psychology, 94*, 795-809.

Anderman, E. M., & Anderman, L. H. (2009). *Classroom motivation*. Boston: Pearson.

Anderman, E. M., Eccles, J. S., Yoon, K. S., Roeser, R. W., Wigfield, A., & Blumenfeld, P. (2001). Learning to value math and reading: Individual differences and classroom effects. *Contemporary Educational Psychology, 26*, 76-95.

Anderman, E. M., Griessinger, T., & Westerfield, G. (1998). Motivation and cheating during early adolescence. *Journal of Educational Psychology, 90*, 84-93.

Anderman, E. M., & Maehr, M. L. (1994). Motivation and schooling in the middle grades. *Review of Educational Research, 64*(2), 287-309.

Anderman, E. M., & Young, A. J. (1994). Motivation and strategy use in science: Individual differences and classroom effects. *Journal of Research in Science Teaching, 31*(8), 811-831.

Anderson, R. D. (2007). Inquiry as an organizing theme for science curricula. In In S. K Abell & N. G. Lederman (Eds.). *Handbook of Research on Science Education* (pp. 807-830). Mahway, NJ: LEA.

Barab, S. A., & Hay, K. E. (2001). Doing science at the elbows of experts: Issues related to the science apprenticeship camp. *Journal of Research in Science Teaching, 38*(1), 70-102.

Battistich, V., Solomon, D., Watson, M., & Schaps, E. (1997). Caring school communities. *Educational Psychologist, 32*, 137-151.

Bell, B (2007). Classroom assessment of science learning. In S. K Abell & N. G. Lederman (Eds.). *Handbook of Research on Science Education* (pp. 965-1006), Mahway, NJ: LEA.

Bereiter, C., & Scarmadalia, M. (1987). The psychology of written composition. Hillsdale, NJ: Lawrence Erlbaum Associates.

Blumenfeld, P., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. S. (1991). Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning. *Educational Psychologist, 26*, 369-398.

Bråten, I. & Strømsø, H. I. (2006). Epistemological beliefs, interest, and gender as predictors of Internet-based learning activities. *Computers in Human Behavior*, *22*, 1027-1042.

Brem, S. K., Ranney, M. & Schindel, J. (2003). Perceived consequences of evolution: College students perceive negative personal and social impact of evolutionary theory. *Science Education, 87*(2), 181.206.

Britton, E. D. & Schneider, S. A. (2007). Large-scale assessments in science education. In S. K Abell & N. G. Lederman (Eds.). *Handbook of Research on Science Education* (pp. 1007-1040), Mahwah, NJ: LEA.

Brown, B. (2004). Adolescents' relationships with peers. In R. Lerner & L. Steinberg (Eds.), *Handbook of adolescent psychology* (pp. 363-394), New York: Wiley.

Cacioppo, J. T., Petty, R. E, Feinstein, J. A., & Jarvis, W.B.G. (1996). Dispositional differences in cognitive motivation: The life and times of individuals varying in need for cognition. *Psychological Bulletin, 119*(2), 197-253.

Chan, C., Burtis, J., & Bereiter, C. (1997). Knowledge building as a mediator of conflict in conceptual change. *Cognition and Instruction, 15*, 1–40.

Chi, M. T. H. (2000). Self-explaining expository texts: The dual processes of generating inferences and repairing mental models. In R. Glaser (Ed.), Advances in instructional psychology (pp. 161–237). Mahwah, NJ: Erlbaum.

Chi, M.T.H. (2005). Common sense conceptions of emergent processes: Why some misconceptions are robust. *Journal of the Learning Sciences, 14*, 161-199. Chi, M. T. H., & Glaser, R., (1985). *Problem-solving ability.* In R. J. Sternberg (Eds)., Human abilities: An information processing approach (pp. 227-250). New York: Freeman.

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schoolsA theoretical framework for evaluating inquiry tasks. *Science Education, 86*(2), 175-218.

Darling-Hammond, L., & McLaughlin, M.W. (1995). Polices that support professional development in an era of reform. *Phi Delta Kappan, 76*, 597.

Davis, H. A. (2003). Conceptualizing the role and influence of student-teacher relationships on children's social and cognitive development. *Educational Psychologist, 38*, 207-234.

Davis, H. A., Ashley, S. M., & Couch, K. N. (2003). *Middle school teachers' concpetions of their relationships with their students*. Paper presented at the American Psychological Association.

Deci, E., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior.* New York: Plenum.

Deci, E. L., & Ryan, R. M. (1994). Promoting sself-determined education. *Scandinavian Journal of Educational Research, 38*(1), 3-14.

Delpit, L. (1995). *Other people's children: Cultural conflict in the classroom*. New York: New Press.

Dole, J. A. & Sinatra, G. M. (1998). Reconceptualizing change in the cognitive construction of knowledge. *Educational Psychologist*, *33*(2/3), 109-128.

Duit, R. Treagust, D. F., & Widodo, A. (2008). Teaching science for conceptual change: Theory and Practice. In S. Vosnidou (Ed.). *International Handbook of Conceptual Change* (pp. 629-646), NY, NY: Routledge.

Duschl, R. A. & Grandy, R. E. (2008) *Teaching scientific inquiry: Recommendations from research and implementation*. Rotterdam, Netherlands: Sense Publications.Duschl, R., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education, 38,* 39–72.

Dweck, C. S., & Leggett, E. L. (1988). A social-cognitive approach to motivation and personality. *Psychological Review, 95*(2), 256-273.

Eccles (Parsons), J., Adler, T. F., Futterman, R., Goff, S. B., Kaczala, C. M., Meece, J. L., et al. (1983). Expectancies, values, and academic behaviors. In J. T. Spence (Ed.), *Achievement and achievement motivation* (pp. 75-146). San Francisco: Freeman.

Eccles, J. (1984). Sex differences in achievement patterns. *Nebraska Symposium on Motivation, 32*, 97-132.

Eccles, J. S. (1994). Understanding women's educational and occupational choices: Applying the Eccles et al. model of achievement-related choices. *Psychology of Women Quarterly, 18*(4), 585-609.

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School Engagement: Potential of the Concept, State of the Evidence. *Review of Educational Research, 74*(1), 59-109.

Hayes, J. (1996). A new framework for understanding cognition and affect in writing. In M. Levy & S. Randsdell (Eds.), *The science of writing: Theories, methods, individual differences, and applications* (pp. 1-27). Mahwah, NJ: Lawrence Erlbaum Associates.

Hayes, J., & Flower, L. (1980). Identifying the organization of writing processes. In L. Gregg & E. Steinberg (Eds.), *Cognitive processes in writing* (pp. 3-30). Hillsdale, NJ: Lawrence Erlbaum Associates.

Jonassen, D. (2008). Model building for conceptual change. In S. Vosnidou (Ed.). *International Handbook of Conceptual Change* (pp. 676-693). NY, NY: Routledge.

Garet, M.S., Porter, A.C., Desimone, L., Birman, B.F., & Yoon, K.S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal, 38*, 915-945.

Gentner, D., & Stevens, A. L. (Eds.). (1983). *Mental models*. Hillsdale, NJ: Erlbaum.

Graham, S. (2006). Writing. In P.A. Alexander & P.H. Winne (Eds.), *Handbook of educational psychology*, 2nd Edition (pp. 457-478). Mahwah, NJ: Lawrence Erlbaum Associates.

Greene, J.A., & Azevedo, R. (2007). Adolescents' Use of Self-Regulatory Processes and Their Relation to Qualitative Mental Model Shifts While Using Hypermedia. *Journal of Educational Computing Research, 36*, 125-148.

Guzzetti, B. J., Snyder, T. E., Glass, G. V., & Gamas, W. S. (1993). Promoting conceptual change in science: A comparative meta-analysis of instructional interventions from reading education and science education. *Reading Research Quarterly, 28*, 117-155.

Goldstone, R. L., & Sakamoto, Y. (2003). The transfer of abstract principles governing complex adaptive systems. *Cognitive Psychology, 46*, 414-466.

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist, 41*, 111-127.

Hidi, S., Weiss, J., Berndorff, D., & Nolan, J. (1998). The role of gender, instruction and a cooperative learning technique in science education across formal and informal settings. In L.Hoffmann, A. Krapp, K. A. Renninger, J. Baumert (Eds.), Interest and learning: Proceedings of the Seeon conference on interest and gender (pp. 215–227). Kiel, Germany: IPN.

Hemlo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*, 235–266.

Higgins, T.E., & Spitulnik, M.W. (2008). Supporting teachers' use of technology in science instruction through professional development: A literature review. *Journal of Science Education and Technology, 17*, 511-521.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67*(1), 88-140.

Houston, J.E., & Smith, E.V. (2008). Relationship of candidate communication and organization skills to oral certification exam scores. *Evaluation and the Health Professions, 31*, 404-418.

Inhelder, B., & Piaget, J. (2008). Adolescent thinking. In D.L. Browning (Ed.), *Adolescent identities: A collection of readings* (pp. 207-220). Analytic Press/Taylor & Francis Group: New York.

Jackson, S., Stratford, J., Krajcik, S., & Soloway, E. (1996). Making system dynamics modeling accessible to pre-college science students. *Interactive Learning Environments, 4*, 233–257.

Kardash, C. M. (2000). Evaluation of an undergraduate research experience: Perceptions of undergraduate interns and their faculty mentors. *Journal of Educational Psychology, 92*(1), 191-201.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: an analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, 41(3), 75-86.

Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. *Science Education, 77,* 319–337.

Kuiper, E., Volman, M., & Terwel, J. (2005). The web as an information resource in K-12 education: Strategies for supporting students in searching and processing information. *Review of Educational Research*, 75, 285-313.

Ladd, G.W., Herald-Brown, S.L., & Reiser, M. (2008). Does chronic classroom peer rejection predict the development of children's classroom participation during the grade school years? *Child Development, 79,* 1001-1015.

Lederman, N. G. (2007). Nature of science: Past, present, and future. In S. K Abell & N. G. Lederman (Eds.). *Handbook of Research on Science Education* (pp. 831-880), Mahway, NJ: LEA.

Lowe, P. & Fisher, Dl. L. (2000). Peer power: The effect of group work on assessment on students attitudes in science. SAMEpapers, 2000, 129-147.

Maehr, M. L., & Midgley, C. (1996). *Transforming school cultures*. Boulder, CO: Westview Press.

Maggioni, L., & Parkinson, M.M. (2008). The role of teacher epistemic cognition, epistemic belifs, and calibration in instruction. *Educational Psychology Review, 20*, 445-461.

Marcia, J. (1966). Development and validation of ego identity status. *Journal of Personality and Social Psychology, 3*, 551-558.

Marcia, J. (1980). Identity in adolescence. In J. Adelson (Ed.), *Handbook of adolescent psychology* (pp. 159-187), New York: Wiley.

Mason, L., & Boldrin, A. (2008). Epistemic metacognition in the context of information searching on the Web. In M. S. Khine (Ed.), *Knowing*, *knowledge and beliefs*: *Epistemological studies across diverse cultures* (pp. 377- 404). New York: Springer.

Mason, L, Boldrin, A. & Ariasi, N. (in press). Searching the Web To Learn about a Controversial Topic: Are Students Epistemically Active? *Instructional Science.*

Mason, L., Boldrn, A., & Zurlo, G. (2006). Epistemological understanding in different judgment domains: Relationships with gender, grade level, and curriculum, *International Journal of Educational Research, 45*, 43–56.

Mayer, R. E. (1998). Cognitive, metacogntive, and motivational aspects of problem solving. *Instructional Science 26*, 49–63.

Mayr, E. (1991). One long argument: *Charles Darwin and the genesis of modern evolutionary thought*. Cambridge, MA: Harvard University Press.

Meichenbaum, D., Burland, S., Gruson, L., & Cameron, R. (1985). Metacognitive assessment. In S. Yussen (Ed.), *The growth of reflection in children* (pp. 1-30). Orlando: Academic Press.

Midgley, C., Kaplan, A., & Middleton, M. J. (2001). Performance-approach goals: Good for what, for whom, under what circumstances, and at what cost? *Journal of Educational Psychology, 93*(1), 77-86.

Mottet, T.P., Ruben, G., Beebe, S.A., Houser, M.L., Summer, J., & Furler, L. (2008). Instructional communication predictors of ninth-grade students' affective learning in math and science. *Communication Education, 57,* 333-355.

Nadelson, L. (in press). How true inquiry can happen in k-16 science education. *The Science Educator.*

National Center for Education Statistics (2007). Trends in international mathematics and science study. Washington, DC: IES [available at http://nces.ed.gov/timss/results07_science07.asp].

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

Nicholls, J. G. (1989). *The competitive ethos and democratic education*. Cambridge: Harvard Univerity Press.

Nolen, S. B., & Haladyna, T. M. (1990). Motivation and studying in high school science. *Journal of Research in Science Teaching, 27*, 115-126.

Nussbaum, E.M., & Bendixen, L.M. (2003). Approaching and avoiding arguments: The role ofepistemological beliefs, need for cognition, and extraverted personality traits. *Contemporary Educational Psychology, 28,* 573–595.

Nussbaum, E.M., & Jacobson, T.E. (2004, July). *Reasons that students avoid intellectual arguments*. Poster session presented at the annual meeting of the American Psychological Association, Honolulu, HI.

Nussbaum, E. M. & Sinatra, G. M. (2003). Argument and conceptual engagement. *Contemporary Educational Psychology, 28*, 384-395.

Nussbaum, E. M., Sinatra, G. M., & Poliquin, A. (2008). The role of epistemological beliefs and scientific argumentation in promoting conceptual change. *International Journal of Science Education, 30(15),* 1977-1999.

Pajares, F. (2003). Self-efficacy beliefs, motivation, and achievement in writing: A review of the literature. Reading and Writing Quarterly, 19, 139-158.

Pajares, F., & Valiante, G. (2001). Gender differences in writing motivation and achievement of middle school students: A function of gender orientation? *Contemporary Educational Psychology, 26,* 366-381.

Paris, S. G., Lipson, M. Y. & Wixson, K. K. (1983). Becoming a strategic reader. *Contemporary Educational Psychology,8*, 293-316.

Paris, S. G., Lawton, T. A., & Turner, J. C. (1992). Reforming achievement testing to promote students' learning. In C. Collins & J. N. Mangieri (Eds.), *Teaching* *thinking: An agenda for the twenty-first century* (pp. 223-241). Hillsdale: Lawrence Erlbaum Associates.

Patrick, H., Anderman, L.H., Breuning, P., & Duffin, L.C. (2009). *Teaching educational psychology to preservice teachers*. Manuscript in preparation.

Pintrich, P. R. (2000). Multiple goals, multiple pathways: The role of goal orientation in learning and achievement. *Journal of Educational Psychology, 92*(3), 544-555.

Pintrich, P. R. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 451–502). San Diego, CA: Academic.

Pintrich, P.R., & Schunk, D.H. (2002). *Motivation in education: Theory, research, and applications* (2nd ed.). Upper Saddle River: Merrill/Prentice Hall.

Renninger, K. A. (in press). *Interest and Identity Development in Instruction: An Inductive Model.* Educational Psychologist.

Resnick, M. D., Bearman, P. S., Blum, R. W., Bauman, K. E., Harris, K. M., Jones, J., et al. (1997). Protecting adolescents from harm: Findings from the National Longitudinal Study on Adolescent Health. *Journal of the American Medical Association, 278*, 823-832.

Roeser, R. W., Midgley, C., & Urdan, T. (1996). Perceptions of the school psychological environment and early adolescents' psychological and behavioral functioning in school: The mediating role of goals and belonging. *Journal of Educational Psychology, 88*, 408-422.

Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency for children in knowledge-building: A challenge for the design of new knowledge media. *Journal of the Learning Sciences, 1*, 37-68.

Scardamalia, M., & Bereiter, C. (1993). Technologies for knowledge-building discourse. *Communications of the ACM, 36*(5), 37-41.

Schunk, D.H., & Ertmer, P.A. (1999). Self regulatory processes during computer skill acquisition: Goal and self-evaluative influences. *Journal of Educational Psychology, 91*, 251-260.

Sá, W., Kelley, C., Ho, C., & Stanovich, K. E. (2005). Thinking about personal theories: Individual differences in the coordination of theory and evidence. *Personality and Individual Differences, 38,* 1149-1161.

Sandoval, W. A., & Reiser, B. J. (2004). Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education, 88*(3), 345-372.

Schunk, D.S., & Zimmerman, B.J. (2008). *Motivation and self-regulated learning: Theory, research, and applications*. Mahwah: Lawrence Erlbuam.

Settlage, J. (2007). Demythologizing science teacher education: Conquering the false ideal of open inquiry. *Journal of Science Teacher Education*, *18*, 461–467.

Sinatra, G. M. & Nadelson, L. (in press). *Science and religion: Opposite ends of core epistemological continua*? In R. Taylor & M. Ferrari (Eds.). Epistemology and Science Education: Understanding the Evolution vs. Intelligent Design Controversy.

Sinatra, G. M. & Kardash, C. M. (2004). Teacher candidates' epistemological beliefs, dispositions, and views on teaching as persuasion. *Contemporary Educational Psychology, 29*, 483-498.

Slavin, R.E. (1995). Cooperative learning (2nd ed.). Boston: Allyn & Bacon.

Slavin, R.E., & Cooper, R. (1999). Improving intergroup relations: Lessons learned from cooperative learning programs. *Journal of Social issues, 55*, 647-663.

Slotta, J. D. & Chi, M.T.H. (2006). The impact of ontology training on conceptual change: Helping students understand the challenging topics in science. *Cognition and Instruction, 24*, 261-289.

Stanovich, K. E. (1999). *Who is rational? Studies of individual differences in reasoning*. Mahwah, NJ: Erlbaum.

Sternberg, R. J. (1997). *Thinking Styles*. New York, NY: Cambridge University Press.

Sternberg, R. J. (1999). *Handbook of Creativity*. New York, NY: Cambridge University Press.

Sternberg, R. J. (2006). The nature of creativity. *Creativity Research Journal, 18*(1), 87-98.

Treagust, D. F., Jocobowitz, R., Gallagher, J. L., & Parker, J. (2001). Using assessment as a guide in teaching for understanding: A case study of a middle school science class learning about sound. *Science Education, 85*(2), 137-157.

Vogel, G. (2007). Science education: Global review faults U.S. curricula, *Science, 274*(5286), 335.

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes.* Cambridge, MA: Harvard University Press.

Wigfield, A., & Eccles, J. S. (1992). The development of achievement task values: A theoretical analysis. *Developmental Review, 12*(3), 265-310.

Yumusak, N., SUngur, S., & Cakiroglu, J. (2007). Turkish high school students' biology achievement in relation to academic self-regulation. *Educational Research and Evaluation, 13*, 53-69.

Zimmerman, B.J. (2000). Attaining self-regulation: A social cognitive perspective. n M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 451–502). San Diego, CA: Academic.

Zimmerman, B.J. (2001). Theories of self-regulated learning and academic achievement: An overview and analysis. In B.J. Zimmerman & D.H. Schunk (Eds.), *Self-regulated learning and academic achievement: Theoretical perspectives* (2nd ed., pp. 1-38). Mahwah: Lawrence Erlbaum Associates.

Zimmerman, B.J., & Risemberg, R. (1997). Becoming a self-regulated writier: A social cognitive perspective. Contemporary Educational Psychology, 22, 73-101.