

Autonomy, Competence, and Intrinsic Motivation in Science Education: A Self-Determination Theory Perspective

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Abstract

JASON PAINTER: *Autonomy, Competence, and Intrinsic Motivation in Science Education: A Self-Determination Theory Perspective*
(Under the direction of Judith Meece)

The purpose of this study was to examine a proposed motivational model of science achievement based on self-determination theory. The study relied on U.S. eighth-grade science data from the 2007 Third International Mathematics and Science Study to examine a structural model that hypothesized how perceived autonomy support, perceived competence in science, intrinsic motivation, and science achievement related to each other. Mother's education and student gender were used as controls. Findings showed that the hypothesized model provided a good fit to the data. The strongest direct effect on science achievement was students' perceived competence in science. Student intrinsic motivation was shown to have a surprisingly negative effect on science achievement. Autonomy support had positive direct effects on students' perceived competence in science and intrinsic motivation and had indirect positive effects to science achievement. Results and implications for science education are discussed.

This dissertation is dedicated to my wife, Sarah, and to our children, Kinsey, Kerrigan,
Jackson, Mary Catherine, and Henry.

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I. Introduction

An important feature of America's efforts to improve economic competitiveness is the presence of a capable scientific and technological workforce. The alarm has sounded regarding the future ability of the United States to generate the science and engineering talent to sustain economic growth. Precollege science instruction plays a critical role in relation to the supply of scientific and technical personnel. A basic science education is considered necessary not only for those who will pursue a science major at the college level, but it also is important for citizens within society to understand evolving scientific and technical issues.

President Barack Obama called the results from the 2009 Program for International Student Assessment (PISA) in science a new "Sputnik moment" (Organization for Economic Cooperation and Development [OECD], 2010). The PISA results underscored the concern that too few U.S. students are prepared to become engineers, scientists and physicians, and that the country is losing ground to international competitors. America's 15-year-olds currently rank 25th in math and 17th in science among the 34 OECD nations (Fleischman, Hopstock, Pelczar, & Shelley, 2010).

Other indicators also reveal troubling national trends in the state of precollege science education. Consistent with PISA results, the average scores of U.S. students on the Trends in International Mathematics and Science Study (TIMSS) from 1995 to 2007 remained flat (Gonzales et al., 2008). The 2009 National Assessment of Educational Progress (NAEP) in science revealed that only 34% of fourth graders, 30% of eighth graders, and 21% of 12th graders performed at or above the proficiency level in science (National Center for Education

Statistics [NCES], 2011). Even more distressing, only 1% of fourth graders, 2% of eighth graders, and 1% of 12th graders performed at an advanced level (NCES, 2011).

To improve achievement and engagement in science, researchers must study and understand the factors that affect them. Many factors have been shown to affect student engagement and achievement, including student background, teacher background, teaching practices, curricula, classroom climates, home environment, and school environments. Motivation researchers have identified various factors related to engagement and achievement including students' achievement goal orientations (Nicholls, 1984), beliefs of success and conception of task values (Eccles, Adler, Futterman, Goff, Kaczala, 1983), interest in content (Renninger, Hidi, & Krapp, 1992), and psychological needs (Deci & Ryan, 1985; Ryan & Deci, 2000). Through the studies of various motivational constructs, we have gained knowledge about the origins of student achievement motivation.

Conceptual Framework for the Study

This study is guided by a self-determination theory framework (SDT) (Deci & Ryan, 1985; Ryan & Deci, 2000). SDT is a theory of human motivation that attempts to account for the energy and direction of behavior. SDT is an organismic theory that states that individuals do not passively react to the environment; they instead actively explore and adapt to their surroundings. According to SDT, there are three primary psychological needs: autonomy (i.e., feeling free to choose one's own behavior), competence (i.e., interacting effectively with one's environment), and relatedness (i.e., feeling meaningfully connected to others) that fuel this exploration and adaptation. Conditions that allow satisfaction of these three primary psychological needs support intrinsic motivation (i.e., self-determined autonomous behavior), and conditions that thwart the satisfaction of these psychological needs undermine intrinsic motivation (Ryan, Deci, & Grolnick, 1995).

SDT also provides an integrated approach to studying the simultaneous relationship of basic human needs and social-cognitive influences. SDT is distinctive in its structure to allow empirical examinations of the relationship between human innate needs and motivation.

Statement of the Problem

Systemic science education reform efforts have resulted in overall achievement in science that is disappointing. Research and literature in the field of science education has focused almost exclusively on attitudes toward science paying little attention to research in the field of achievement motivation (Breakwell & Beardsell, 1992; Crawley & Black, 1992; Koballa Jr., 1995; Oliver & Simpson, 1988; Piburn, 1993; Talton & Simpson, 1986).

The 1994 *Handbook of Research on Science Teaching and Learning* (Gabel, 1994) referenced the word *motivation* only three times while the word *attitude* appeared in more than 45 subject index listings and sublistings. The most recent version of this handbook (Abell & Lederman, 2007) included one chapter titled, “Attitudinal and Motivational Constructs.” This section on motivation highlighted various motivational constructs but referenced only a handful of studies within the field of science education—all of which were written by motivation researchers. It is surprising that so little work has been done in the field of science education to identify the nature and style of teaching and learning activities that engage students. Does the application of reforms in science education to the classroom environment lead to increased student motivation and achievement? To improve science engagement and achievement, it is critical to study and try to understand the motivational factors that affect engagement and achievement in science.

Purpose of this Study

The purpose of this study is to examine a proposed motivational model of science achievement based on self-determination theory. The model will be assessed using data from the Trends in International Mathematics and Science Study (TIMSS, 2007). Although TIMSS is an international assessment and survey conducted by the International Association for the Evaluation of Education Achievement (IEA), which includes 59 countries, this study relies on the U.S. eighth-grade subsample of the assessment and survey population. The selected sample includes 6,946 students in 150 public and private schools during the 2007 school year.

The proposed model will examine a specific aspect of teacher-student interactions, autonomy support, and its relation to students' perceived competence in science, intrinsic motivation, and science achievement. The proposed model and hypotheses for this study will be presented in Chapter 2 following the review of the literature.

Summary

In summary, this study relies on data from TIMSS 2007 to examine a motivational model of science achievement based on self-determination theory. The study is grounded in self-determination theory and provides a possible mechanism to improve science instruction and achievement in U.S. schools. It is anticipated that this study's findings will inform science educators and policymakers on the value of tending to motivational factors in science classrooms.

II. Review of the Literature

In this chapter, the theoretical and research literatures on self-determination theory are reviewed to show how the current study will contribute to existing literature. First, the historical precursors to self-determination theory are explored and discussed. Second, self-determination theory is reviewed and its three basic innate psychological needs are considered. Finally, the needs of autonomy and competence are explored further with an emphasis on their relation to intrinsic motivation, achievement, and educational settings.

Historical Precursors to Self-Determination Theory

In 1949, Harry F. Harlow, professor of psychology at the University of Wisconsin, studied eight rhesus monkeys for a two-week experiment on learning. Harlow devised a simple mechanical puzzle that required three steps to solve: pull out the vertical pin, undo the hook, and lift the hinged cover.

Harlow placed the puzzles in the monkeys' cages to initially observe their reactions and to prepare them for tests of their problem-solving ability at the end of the two weeks. However, almost immediately, something unexpected happened. Unbidden by outside urging and unprompted by Harlow, the monkeys began playing with the puzzles with focus, determination, and what looked like enjoyment. In short order, they began figuring out how the puzzles worked. By the time Harlow tested the monkeys on Days 13 and 14 of the experiment, these eight primates had become adept at solving puzzles. They solved the puzzles frequently and quickly. Two thirds of the time, the monkeys solved the code in 60 seconds or less.

At the time, scientists knew that two drives powered behavior. The first drive was identified as the biological drive—the concept that humans as well as animals possessed drives that sought to maintain homeostasis. For instance, humans ate to satisfy their hunger, drank to quench their thirst, and copulated to satisfy their sexual urges. In response to the need to satisfy the deprivation of an essential element (such as food, air, and water) a drive is activated, causing an organism to behave in complex ways. However, with the rhesus monkeys, the urge to satisfy essential needs was not present, and Harlow reported, “But the solution did not lead to food, water, or sex gratification” (Harlow, Harlow, & Meyer, 1950, p. 232).

The only other known drive did not solve Harlow’s dilemma either. Biological drive came from within; the other known drive came from without—an incentive drive where an external goal motivates behavior. Hull (1943) postulated that large rewards led to better learning than small rewards; a worker would work harder if he or she was promised a pay raise and a student would study longer with the prospect of getting an A on the test. But this drive did not account for the monkeys’ actions either. As Harlow wrote, “The behavior obtained in this investigation poses some interesting questions for motivation theory, since significant learning was attained and efficient performance maintained without resort to special or extrinsic incentives” (Harlow et al., 1950, p. 231).

Harlow offered a new theory—a purported third drive: “The performance of the task,” he said, “provided intrinsic reward” (Harlow et al., 1950, p. 232). In essence, the monkeys solved the puzzles simply because they found it gratifying to solve puzzles. They enjoyed it. The joy of the task was its own reward, and intrinsic motivation was coined.

If intrinsic motivation was the third drive, then surely it was subordinate to the other two drives: biological and incentive. To test this notion, Harlow deprived several of the

monkeys of food for 22 hours. He then baited the puzzle latch with a bit of food in the presence of the deprived animals, and returned it to them. The monkeys reportedly began playing with the previously mastered puzzle without regard to the manipulations necessary to open it. When it was opened and the food eaten, the monkeys demonstrated no interest in continued play with the puzzle. Harlow found that if the monkeys were rewarded they actually made more errors and solved the puzzles less frequently. "Introduction of food in the present experiment served to disrupt performance, a phenomenon not reported in the literature" wrote Harlow et al. (1950). Of this new drive, intrinsic motivation, he said, "It would appear that this drive...may be as basic and strong as the [other] drives. Furthermore, there is some reason to believe that [it] can be efficient in facilitating learning" (pp. 233-234).

This third drive was considered in the psychological literature but remained on the periphery of behavioral science. Then in 1968, de Charms cited Harlow's study as evidence of the ill effects of extrinsic reinforcers, as well as support for a theory of cognitive re-evaluation of the locus of causality for behavior. De Charms (1968) gave Heider (1958) credit for the idea that locus of causality for behavior can be internal or external; however, de Charms developed the concept of personal causation, which referred to "the desire to be the master of one's fate" (p. 270). Further de Charms hypothesized that "when man perceives his behavior as stemming from his own choice he will cherish that behavior and its results; when he perceives his behavior as stemming from the dictate of external forces, that behavior, and its results, although identical in other respects of behavior of his own choosing, will be devalued" (p. 273).

In the summer of 1969, Edward Deci, a Carnegie Mellon University psychology graduate student in search of a dissertation topic, was intrigued by motivation but suspected

that scholars and business professionals misunderstood it. Deci conducted a study in which he placed two groups of college students in rooms with a Soma cube (a puzzle similar to a Rubik's cube) and several magazines. One group was offered money for each design they could assemble with the cube, while the other group was merely asked to work on the puzzle. After a specified time elapsed, Deci told the students that their time was up, and for the next 10 minutes he observed them in secret and found that paid participants were more likely to quit the puzzle and pick up the magazines, whereas unpaid participants continued to work on the puzzle. Thus, the focus of the paid participants had shifted to the compensation, an extrinsic motivator, whereas the unpaid participants remained motivated by the inherently engaging task. In short, working on an interesting activity in order to earn a reward decreased intrinsic motivation, implying that tangible, monetary rewards were not additive but instead were negatively interactive with intrinsic motivation. Deci also found that providing participants with positive feedback about performance led to enhancements in intrinsic motivation relative to no feedback.

This initial study put Deci on a lifelong journey to understand a different way of thinking about humans' internal resources for motivation and led to the development of self-determination theory (SDT). Deci and other researchers conducted a plethora of laboratory experiments that replicated his initial results, as summarized in narrative (Ryan, Mims, & Koestner, 1983) and meta-analytic (Deci, Koestner, & Ryan, 1999) reviews. The following section will explore the basic tenants of self-determination theory and the basic psychological needs the theory proposes as innate in every individual.

Self-Determination Theory

Self-determination theory (SDT) (Deci & Ryan, 1985; Deci & Ryan, 1991; Ryan & Deci, 2000) explains human motivation by focusing on the importance of human internal

resources for development and behavior regulation. In this theory, humans are assumed to have active, endogenous tendencies toward psychological growth and integration. As such, humans innately strive to assimilate their social and physical worlds, to discover new perspectives, and to actively engage with and integrate themselves into a larger social whole. SDT postulates that the desire to meet one's innate needs is the fundamental motive for human behavior, but motivation cannot be taken for granted because environmental factors can either encourage or thwart the innate tendency to act to satisfy the needs (Ryan & Deci, 2002). SDT holds that satisfaction of three basic innate psychological needs is critical for self-determined motivation and adaptive consequences.

Basic innate psychological needs in SDT. Among modern theories of motivation, SDT is unique in its inclusion of basic psychological needs, a fundamental source of mental energy for human behaviors often manifested in social settings such as classrooms, playgrounds, and other similar environments. In SDT, innate needs for competence, autonomy, and relatedness serve as the cornerstones of human motivation (Deci & Ryan, 1985).

Deci and Ryan (2000) trace the roots of the basic psychological needs included in SDT to early needs theories of Hull (1943) and Murray (1938). Hull explained behavior and motivation through reactions to deficits of innate physiological needs for air, water, food, and the like. From Hull, Deci and Ryan wrote that they borrowed the concept of needs being "innate organismic necessities" (p. 229), which were necessary for the health and well-being of individuals, except that in SDT, needs are psychological rather than physiological. Murray outlined a number of psychogenic needs including achievement, recognition, aggression, and affiliation. He considered these psychogenic needs to be secondary to viscerogenic needs such as air, water, food, sex, and harm avoidance. Murray wrote that he

did not suppose that these psychogenic needs were fundamental, although some may be innate. He did not, however, expand on which ones may be innate or on why. Deci and Ryan pointed out that Murray's psychogenic needs were not necessarily essential to the optimal functioning of humans, nor were they necessarily innate, and thus were very different from the psychological needs in SDT.

Needs are defined by Deci and Ryan (2000) as "*innate psychological nutriments that are essential for ongoing psychological growth, integrity, and well-being*" (p. 229, italics in original source). Specific requirements for deciding that a construct can be considered a need are implicit in this definition but include the following principles. First, a need is innate and universal. Second, being an essential nutriment means the satisfaction of a need leads to positive consequences but also that the failure to satisfy a need necessarily leads to negative consequences; only constructs that show both of these patterns in empirical studies can be considered basic psychological needs. Third, Ryan and Brown (2003) said a need must not be a derivative of any other more basic construct. That is, a need must be "the basic 'satisfier' responsible for the functional advantage regarding growth, integrity or well-being" (p. 73). Ryan and Deci (2002) said that because the criteria cited above were so restrictive, that competence, autonomy, and relatedness were thus far the only psychological constructs that qualify as basic, innate needs in SDT.

Need for competence. In SDT, the need for competence refers to a need to feel confident and effective in one's activities (Ryan & Deci, 2002). It denotes a feeling of competence or perceived competence rather than an objective measure of ability. The more competent individuals perceive themselves in an activity the more intrinsically motivated they will be at that activity (Deci & Ryan, 1985). Since White's (1959) introduction of competence through his construct of effectance motivation, many prominent models of

motivation have included feeling competent or a highly related construct such as self-efficacy as a critical determinant of motivation (e.g., Bandura, 1997; Eccles & Wigfield, 2002; Harter, 2003). With students, the need for competence translates to a desire to feel confident in one's abilities to accomplish academic activities, such as reading tasks or science activities. To maintain a high level of perceived competence, Ryan and Deci maintained that students will seek challenges that are in accordance with their capacities.

Need for autonomy. The need for autonomy represents individuals' inherent desire to feel volitional and to experience a sense of choice and psychological freedom when carrying out an activity (de Charms, 1968; Deci & Ryan, 2000). The need for autonomy according to Ryan, Deci, and Grolnick (1995), refers to "self-rule" or actions that are initiated and regulated by the self. It is the degree to which individuals perceive themselves as the source and initiator of behavior (Ryan & Deci, 2002). The more autonomous individuals perceive themselves in activities, the more intrinsically motivated they will be.

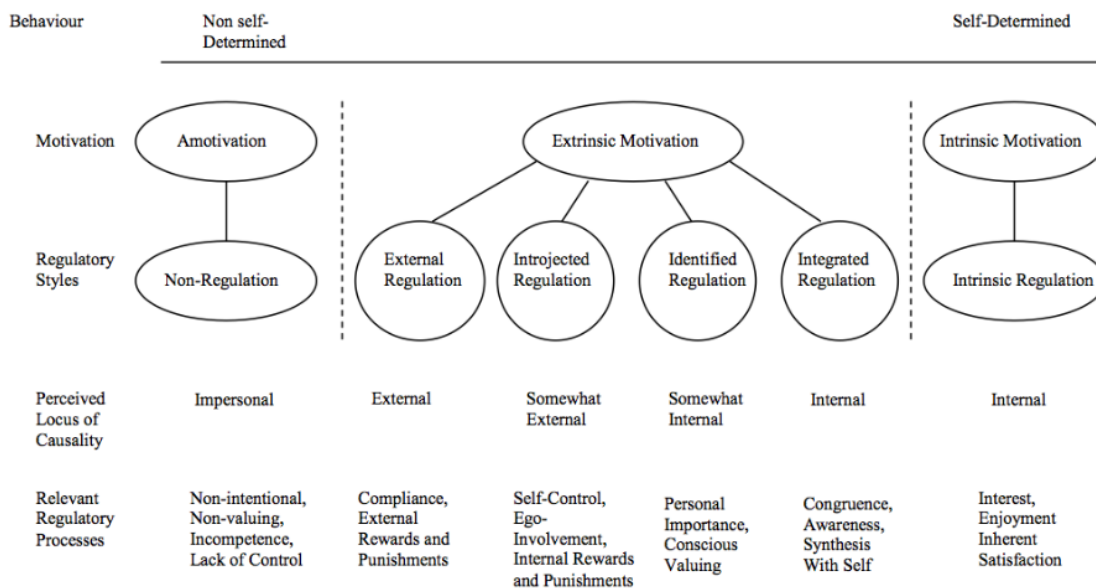
Need for relatedness. The need for relatedness is the need for a "psychological sense of being with others in secure communion or unity" (Ryan & Deci, 2002, p. 7). This conceptualization includes feeling connected and a sense of belongingness with other individuals as well as with one's community. SDT researchers in the field of education have done some work on relatedness. Skinner and Belmont (1993) found that children's perceptions of their teachers' involvement predicted the children's subsequent engagement in class, such that "when children experience teachers as warm and affectionate, children feel happier and more enthusiastic in class" (p. 578). Other research has shown that relatedness with parents and teachers positively predicts students' self-reported motivation in school (Ryan, Stiller, & Lynch, 1994). Wentzel (1997) found that students' perceptions of their teachers as caring predicted students' academic motivation even after taking into account

students' control beliefs, reports of psychological distress, and prior motivation. The more relatedness a person perceives within a community, the more intrinsically motivated that person will be.

The self-determination continuum. Figure 1 presents the self-determination continuum that delineates an understanding of intrinsically and extrinsically motivated behaviors as well as amotivation. The continuum is arranged from left to right in terms of the extent to which the motivation for a behavior emanates from the self (i.e., is autonomous).

Figure 1

The Self-Determination Continuum (Ryan & Deci, 2000, p. 72)



At the left end of the continuum is amotivation, the state of lacking the intention to act. When individuals are amotivated, either they do not act at all or they act passively. Amotivation results from feeling either that they are unable to achieve desired outcomes because of a lack of contingency (Rotter, 1966) or a lack of perceived competence (Bandura,

1977; Deci, 1975) or that they do not value the activity or the outcomes it would yield (Ryan, 1995).

The other five points on the continuum refer to classifications of motivated behavior. Each describes a theoretically, experientially, and functionally distinct type of regulation. At the right end of the continuum is intrinsic motivation, which is when individuals are in a state of doing an activity out of interest and innate satisfaction (Ryan, Deci, & Grolnick, 1995). Extrinsically motivated behaviors are characterized by four types of regulation along the self-determination continuum between amotivation and intrinsic motivation.

Extrinsically motivated behaviors can vary considerably in their relative autonomy via four regulatory styles (i.e., external, introjected, identified, and integrated). Some extrinsically motivated actions are clearly pressured or compelled by outside forces (external and introjected). Conversely, other extrinsically motivated actions can have an internal perceived locus of causality (identified and integrated). Refer to Figure 1 for a description of the relevant regulatory processes associated with each type of motivation or regulatory style.

Intrinsic motivation. As described by the self-determination continuum, in SDT, motivation can be understood in three basic states: intrinsic motivation, extrinsic motivation, and amotivation. Intrinsic motivation is of particular importance to this study. Intrinsic motivation indicates that individuals engage in an activity for the sake of the activity itself and for the satisfaction inherent in performing the activity (Deci & Ryan, 1985). Intrinsic motivation often derives from the person-activity interaction in activities that people find interesting, enjoyable, not boring, and optimally challenging (Ryan & Deci, 2002). In other words, intrinsic motivation energizes a variety of behaviors and the primary rewards for performing these behaviors are the fulfillment of autonomy, competence, and relatedness needs (Deci & Ryan, 1985). Therefore, intrinsic motivation resides in people's needs of

autonomy, competence, and relatedness and is considered the fuel for action to satisfy one's innate needs (Grolnick, Gurland, Jacob, & Decourcey, 2001). The present study will consider only autonomy and competence and their relation to intrinsic motivation and science achievement. Consequently, research on autonomy and competence in educational settings will now be examined.

Autonomy in educational settings. Much empirical work has concluded that a number of key motivation variables are correlated with students' perceptions of autonomy support in the classroom (see Table 1). To support the importance of these student perceptions, researchers asked students to self-report their academic motivation and found that the degree to which students' motivation was self-determined versus controlled predicted the outcomes listed on the left side of Table 1. The right side of Table 1 lists studies that provide evidence that students' achievement, learning, and persistence in school are due in part to teachers' support of their autonomy rather than control of their behavior. These findings are reported across grade levels.

Bao and Lam (2008), Zuckerman, Porac, Lathin, Smith, and Deci (1978), and Swann and Pittman (1977) reported that providing choice about what to do or how to do it enhanced intrinsic motivation. Environments that provide autonomy are considered particularly important during the adolescent years (Eccles & Midgley, 1989; Deci & Ryan, 1985; Ryan, Deci & Grolnick, 1995). Such environments are not without rules and structure but provide some level of choice in selecting goals and the means for achieving them (Newell & Van Ryzin, 2007). Many researchers even suggest that the striving for autonomy is stronger in adolescents than in children (Cobb, 1992; Feldman & Quatman, 1988; Hill & Holmbeck, 1986; Steinberg & Silverberg, 1986).

Table 1

Student Benefits from Autonomous Motivation and Teachers' Autonomy Support

Autonomously Motivated Students		Students with Autonomy-Supportive Teachers	
Educational Benefit	Reference	Educational Benefit	Reference
Higher Academic Achievement	Miserandino, 1996 Flink et al., 1992	Higher Academic Achievement	Flink, Boggiano, & Barrett, (1990) Boggiano et al., 1993
Higher Perceived Competence	Ryan & Grolnick, 1986	Higher Perceived Competence	Deci, Schwartz et al., 1981 Ryan & Grolnick, 1986 Williams et al., 1994
Preference for Optimal Challenge	Shapira, 1976 Boggiano, Main, & Katz, 1988 Pittman et al. 1980	Greater Conceptual Understanding	Benware & Deci, 1984 Boggiano et al., 1993 Flink et al., 1990 Grolnick & Ryan, 1987
Greater Creativity	Amabile, 1985	Greater Creativity	Koestner et al., 1984
Higher Rates of Retention	Vallerand & Bissonette, 1992	Higher Rates of Retention	Vallerand et al., 1997

Zuckerman et al. (1978) found that students who experienced a greater sense of autonomy about experimenter-cued puzzle-solving tasks were more likely to choose to engage in puzzle-solving tasks and spend more time engaged in these tasks during free time. Similarly, Koestner, Ryan, Bernieri, and Holt (1984) showed that empathy and non-control can help maintain intrinsic motivation.

Other studies in educational settings have shown that threats of punishment (Deci & Cascio, 1972), deadlines (Amabile, Dejong, & Lepper, 1976; Reader & Dollinger, 1982), imposed goals (Mossholder, 1980), surveillance (Lepper & Greene, 1975; Pittman, Davey, Alafat, Wetherill, & Kramer, 1980; Plant & Ryan, 1985), competition (Deci, Betley, Kahle, Abrams, & Porac, 1981), and evaluation (Church, Elliot, & Gable, 2001; Ryan, 1982) decreased intrinsic motivation, presumably because they were experienced as controls.

Supporting students' need for autonomy support also has been linked with deeper, more holistic levels of processing, more internalized forms of behavioral self-regulation, and less pressure and more interest and enjoyment in learning tasks (Grolnick & Ryan, 1987). Lopez (2000) found that mastery-oriented academic performance (a more internally regulated behavior) was related to more internalized regulation of learning behaviors, higher intrinsic motivation in learning, and a greater sense of academic competency.

At the university level, Black and Deci (2000) and Williams and Deci (1996) found that autonomy support by instructors improved academic performance and resulted in increases in internal self-regulation of academic tasks. Williams and Deci also reported that medical students who experienced greater autonomy support felt more competent at medical interviewing and were more likely to internalize values espoused by their course instructors.

Competence in educational settings. The need for competence leads people to seek challenges that are optimal for their capacities and to persistently attempt to maintain and enhance those skills and capacities through activity. Competence is not, then, an attained skill or ability. Instead, it is a perception that gives rise to additional social inferences about the self and others, as well as influences affects and social behavior. Competence is a perceived sense of confidence and effectance in action.

Lau and Roeser (2002) found that although cognitive ability was the strongest predictor of high school students' performance on science achievement tests, students' perceived science competence also significantly predicted engagement, achievement, and aspirations. Specifically, with cognitive ability controlled, students' science self-concept uniquely predicted students' classroom engagement, science achievement, and aspirations to pursue science-related college majors and careers.

According to several well-established theories (Atkinson, 1964; Bandura, 1977; Ryan & Deci, 2000), self-perceptions play a vital role in the emergence of motivation in students. If students believe they are likely to be successful, then they should be more motivated to engage in academic activities than students who believe they are not likely to be successful. Motivation to complete tasks should lead students to become more competent, and once students are more competent then their self-perceptions should be higher. Thus, the relationship between self-perceptions, motivation and achievement is a reciprocal one.

Intrinsic motivation for an activity involves engaging in it out of interest. Csikszentmihalyi (1975) and Deci (1975) suggest that one important feature of intrinsically motivating activities is that they represent an optimal challenge given the person's capabilities. Research has shown that people will be attracted to, and will choose, tasks that allow them to improve their performance and skills. For instance, tasks that are easy, that they have already mastered, or extremely difficult, that overtax their skills and are thus almost impossible to master, will not provide an optimally stimulating incentive for students. However, tasks of appropriate difficulty and challenge to their current capabilities will provide the necessary motivating enticement (Shapira, 1976). Providing students with tasks with the appropriate level of difficulty is critical to increasing students' perceived

competence in areas such as science. Making the tasks too easy or too hard could lead to undermining students' motivation and competence.

Self-determination theory and science education. The utility of applying self-determination theory to science education is that it aligns with current reforms in science education (NRC 1996), which place intrinsic motivation and autonomy at the center of change. Science education reforms focus on teaching methods that have alternately been called scientific inquiry, discovery, problem-based, and constructivist (American Association for the Advancement of Science, 1993; National Research Council, 1996). While the particulars of these approaches vary, all involve new roles for teachers and learners. Teachers are now seen as providers of guidance and scaffolding more than sources of control and authority; students are encouraged to abandon passive-uptake roles to become more actively engaged in the learning process (autonomy). Although these reform-based approaches have gained a significant foothold in U.S. teaching policies, they have been found difficult to implement successfully (Roehrig, 2004; Wallace & Kang, 2004; Windschitl, 2004), and their effectiveness in increasing student learning and motivation has been contested (Kirschner, Sweller, & Clark, 2006; Mayer, 2004).

Self-determination theory suggests a possible mechanism underlying the potential success of reform-based science teaching on student learning. A traditional science classroom with the teacher as the center of authority would be less consistent with satisfying individuals' needs for autonomy and competence whereas a reform-oriented science classroom would provide autonomy and satisfaction to students in the learning process. According to self-determination theory, individuals progressively develop intrinsic motivation through their self-evaluations of their competence. Therefore, contextual conditions that support students' autonomy in the classroom, such as taking the student's

perspective, acknowledging the student's feelings and perceptions, providing choice, and giving opportunities for initiative, offer students the possibility to satisfy their sense of competence and lead to improved intrinsic motivation. Therefore, self-determination theory posits the following causal sequence: autonomy support → changes in perceived competence → changes in intrinsic motivation. In other words, students must feel both autonomous and competent to be intrinsically motivated. Past research (Ryan & Deci, 1985, 2000) has shown that autonomous, motivated people show greater self-competence and that autonomous motivation and self-competence affect relevant behaviors (e.g., school achievement). Although this theory addresses other issues, such as relatedness, extrinsic motivation, and self-determination, these issues are not examined in this study.

Rationale for the Study

From the above discussion, it is clear that self-determination theory (SDT) provides a sound theoretical framework on which to investigate the relationship of perceived autonomy support, perceived competence in science, and intrinsic motivation on science achievement among U.S. eighth graders. Building on research reviewed in this chapter, this study relied upon items from the 2007 Third International Mathematics and Science Study to measure the relationships of the following latent constructs and observed variables on science achievement: perceptions of autonomy support, perceived competence in science, and intrinsic motivation. Gender and mother's education will be added as covariates because Mullis, Martin, Fierros, Goldberg, and Stemler (2000) found that there was a significant gender difference in students' perceived competence in science and intrinsic motivation toward science, and that parents' education was positively related to students' perceived competence in science and science achievement.

Research Questions and Hypotheses

This study asked several research questions and posed hypotheses for each. The following section outlines the research questions and hypotheses for this study.

- 1. Does the hypothesized model provide a satisfactory fit to the sample data using the following goodness-of-fit indices: Chi-Square (χ^2), Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Standardized Root Mean Square Residual, (SRMR), and Root Mean Square Error Approximation Index (RMSEA)?* I hypothesized that the model will fit the data satisfactorily.
- 2. Is perceived autonomy support in the classroom significantly related to perceived competence in science?* I hypothesized that students who had a higher perception of autonomy support in the classroom would have a higher perceived competence in science.
- 3. Is perceived autonomy support in the classroom significantly related to intrinsic motivation?* I hypothesized that students who have a higher perception of autonomy support in the classroom would have more intrinsic motivation.
- 4. Is perceived autonomy support in the classroom significantly related to science achievement?* I hypothesized that students who have a higher perception of autonomy support in the classroom would have higher science achievement outcomes.
- 5. Is perceived competence in science significantly related to science achievement?* I hypothesized that students who have a higher perceived competence in science would have higher science achievement outcomes.

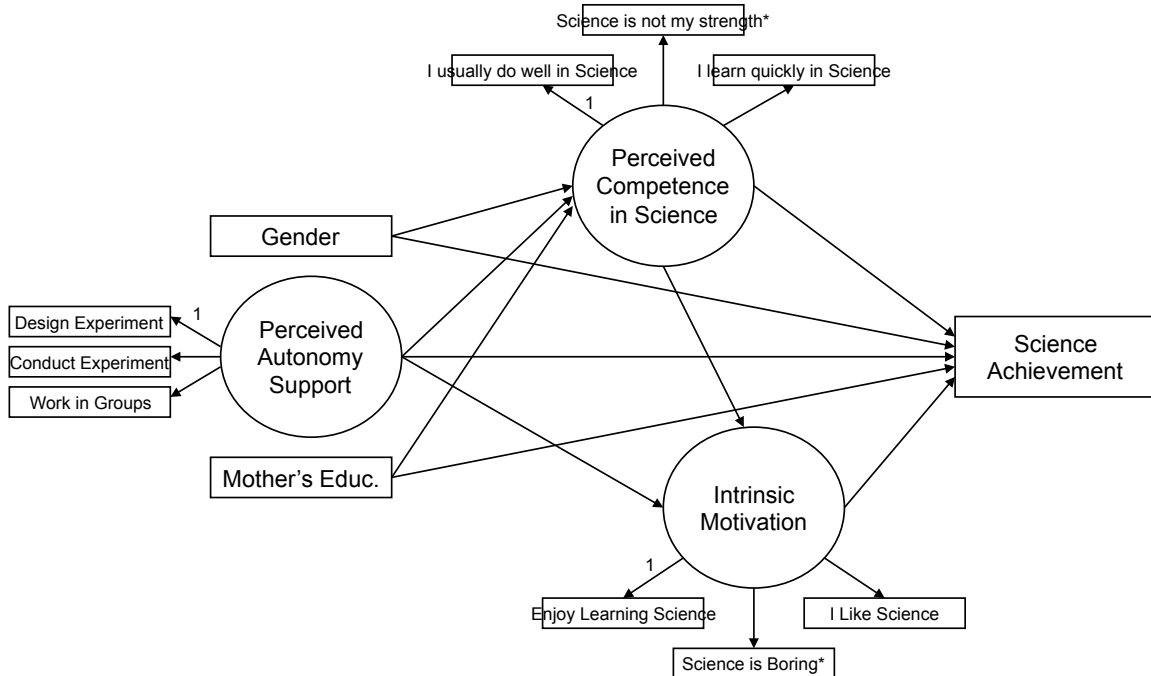
6. *Is intrinsic motivation significantly related to science achievement? I*

hypothesized that students who have more intrinsic motivation would have higher science achievement outcomes.

Mother's education and students' gender were two observed variables used as controls in this study. The full hypothesized structural model is displayed in Figure 2.

Figure 2

Full Hypothesized Model for Science Achievement



Note: Error terms not shown.

III. Methods

This chapter provides descriptions of the Third International Mathematics and Science Study (TIMSS), participants, and the measures used for the analyses. Additionally, this chapter explains the preparation of the data for analysis, including how the dataset was constructed. Next, the procedures for running the structural equation model are provided along with goodness-of-fit indices for these models. The chapter concludes with a summary.

Third International Mathematics and Science Study

This study incorporated data from the TIMSS 2007. TIMSS 2007 was the fourth comparison of mathematics and science achievement conducted by the International Association for the Evaluation of Educational Achievement (IEA), an international organization of national research institutions and governmental research agencies. TIMSS measures over time the mathematics and science knowledge and skills of fourth graders and eighth graders in 59 nations. TIMSS is designed to align broadly with mathematics and science curricula in the participating nations (Gonzalez et al., 2008).

The goal of TIMSS is to provide comparative information about educational achievement across nations to improve teaching and learning in mathematics and science. Conducted on a regular four-year cycle, TIMSS assessed mathematics and science in 1995, 1999, 2003, and 2007. In addition to monitoring trends in achievement for students in fourth grade and eighth grade, TIMSS provides information about relative progress across years as the cohort of students assessed in fourth grade move to eighth grade four years later (e.g., the fourth-grade students of 2003 became the eighth-grade students of 2007).

TIMSS participants. TIMSS 2007's assessment was administered to specific probability samples of students from target populations identified in each nation. The target populations were students enrolled in the fourth or eighth year of formal schooling, counting from the first year of primary school as defined by UNESCO's International Standard Classification of Education (UNESCO, 1999). In most nations, the two samples included fourth-grade and eighth-grade students. However, to avoid testing students who were very young, TIMMS mandated that the average age of children in the grade tested not be below 9.5 years for the fourth year of schooling or 13.5 years for the eighth year of schooling.

To appropriately sample these populations, the basic sampling design was a two-stage stratified cluster design. The first stage consisted of sampling schools. The second stage consisted of sampling intact classrooms from the target grade within the sampled schools. Typically, at each grade, 150 schools and one or two intact classrooms were sampled in each country (Olson, Martin, & Mullis, 2008).

TIMSS assessments. TIMSS assessments were based on assessment frameworks developed after extensive analysis of national curricula with input from an international panel of science and assessment experts and were reviewed by national research coordinators in each nation. The assessment instruments included achievement measures and background questionnaires. The TIMSS 2007 achievement measures assessed content knowledge in science, as well as in three key cognitive processes: knowing, applying, and reasoning. The TIMSS 2007 contextual questionnaires included items to collect information about students' home resources, languages spoken at home, learning habits inside and outside of school, competence and intrinsic motivation, and classroom instructional practice (Olson et al., 2008).

The next sections provide details about the TIMSS 2007 participants and measures selected for the current study. Information about the measurement model and other data preparation is also provided.

Study Participants

The sample for this study included the 6,946 eighth-grade students who participated in the TIMSS 2007 study in the United States. The sample included 13- to 14-year-old students from 239 schools across the United States, with 19.7% in schools in the Northeast, 24.3% in schools in the Southeast, 23.4% in schools in the Midwest, and 32.6% in schools in the West. Some 91.4% of the schools were public and 8.6% private. Students attended school in a variety of community types: 34% in a central city; 39.1% in an urban fringe or large town community type; and 26.9% in a rural or small town. Some 32% of the schools sampled were classified as high-poverty level, and 62.4% were classified as low-poverty level.

The basic demographic characteristics of the student sample were: 50.7% were female; 62.2% were White; 15.7% were Black; 17.4% were Hispanic; 3.7% were Asian or Pacific Islander; and 1.0 % were American Indian or Alaska Native. Some 43.9% of the students participating were eligible for free or reduced-price lunch. Some 34% of the students' mothers had completed college or obtained an advanced degree, and 27% had obtained a high school diploma or GED. Only a small percent (3.3%) of mothers indicated they had not completed high school.

Study Measures

This section describes measures used to assess the constructs and their relationships to one another under investigation. Mother's education and gender were observed variables used as controls in this study. Three latent constructs were developed from the TIMSS

background questionnaire data to test the stated hypotheses of the study. Latent constructs were developed for autonomy support, intrinsic motivation, and perceived competence in science. The outcome variable was science achievement.

Mother’s education. The variable for mother’s education (Momed) is based on the International Standard Classification of Education (ISCED) and focuses on the levels of education completed by the mother. The scale ranges from 1 to 7 and Table 2 describes the ISCED classification scheme.

Table 2

ISCED Educational Classification Scheme

Level	Description
1	Kindergarten and below, did not attend school
2	Elementary school (1 st – 6 th grades)
3	Middle school (7 th – 9 th grades)
4	High school (10 th – 12 th grades), vocational education
5	Community or junior colleges leading to associates degree
6	University or other 4-year program leading to a bachelor’s degree
7	University leading to master’s or doctorate degree

Gender. The variable for gender in the model is categorical with two response options: 0 = girl, 1 = boy.

Autonomy support. The measure of autonomy support assessed students’ perception of autonomy in the science classroom. A latent construct was estimated from student responses to the following questions about science: (a) How often do you design or plan an experiment or investigation in your science lessons (Plan)? (b) How often do you

conduct an experiment or investigation in your science lessons (Conduct)? (c) How often do you work in small groups on an experiment or investigation in your science lessons (Groups)? Each item was rated on a four-point Likert scale: *never* = 1, *some lessons* = 2, *about half the lessons* = 3, and *every or almost every lesson* = 4.

Intrinsic motivation. The index of intrinsic motivation examined whether students found science interesting, enjoyable, and not boring. The index was based on students' responses to the following three statements about science: (a) I enjoy learning science (Enjoy); (b) Science is boring (reverse coded) (Bore); (c) I like science (Like). Each item was rated on a four-point Likert scale: *disagree a lot* = 1, *disagree a little* = 2, *agree a little* = 3, and *agree a lot* = 4.

Perceived competence in science. The index of perceived competence in science referred to the perceived confidence that students have in their capacity to learn science. For science, the index is based on students' responses to the following three statements about science: (a) I usually do well in science (Well); (b) I learn things quickly in science (Quick); (c) Science is not one of my strengths (reverse coded) (Strength). Each item was rated on a four-point Likert scale: *disagree a lot* = 1, *disagree a little* = 2, *agree a little* = 3, and *agree a lot* = 4.

Science achievement. Science achievement was the outcome variable examined in this study. In TIMSS 2007, science achievement was measured using plausible-value technology. This procedure involved computing five separate estimates of each student's score based on the student's responses and background characteristics (Olson et al., 2008). Specifically, items were assembled into a nonoverlapping set of blocks with 10 to 15 items per block. In 2007, the eighth-grade TIMSS assessment included 429 total mathematics and science items distributed across 14 booklets with four blocks each. The TIMSS booklet

design reduced individual testing time to 90 minutes per student plus 30 minutes for the student background questionnaire (Gonzalez et al., 2008). The methods used in TIMSS 2007 are generally similar and originate from methods developed for the National Assessment of Educational Progress (Beaton & Johnson, 1992; Mislevy, Beaton, Kaplan, & Sheehan, 1992; Mislevy, Johnson, & Muraki, 1992; von Davier, Sinharay, Oranje, & Beaton, 2006).

Although this administration method has several advantages, it poses challenges for generating individual proficiency estimates. With plausible-value methodology, student achievement was treated as a missing value and was estimated based on responses to the limited subset of administered cognitive items, as well as on student background characteristics. These estimations were guided by Rubin's (1987) multiple imputation approach to generate a student ability distribution for the population or subpopulation of interest (Beaton & Johnson, 1992; Mislevy, Beaton, et al., 1992; Mislevy, Johnson, et al., 1992; von Davier et al., 2006). For the TIMSS 2007, a fixed number of five individual proficiency estimates was drawn at random from an empirically derived ability distribution.

When conducting analyses of plausible values, two shortcuts often are implemented, both of which are incorrect. For the first alternative, which is considered to be the least problematic of the two methods, researchers often choose to use a singular plausible value such as the first overall science score in TIMSS. When analyzing only one plausible value, the standard errors for statistics of interest are generally underestimated, as the uncertainty associated with the measurement of proficiency distributions is ignored. The second option is to use the mean of the five plausible values as a single estimate of achievement for individuals. Compared to the option of choosing only one plausible value to report, averaging plausible values into a single indicator can even more severely underestimate errors of measurement. Consequently, averages of plausible values should never be used in

analyses (von Davier, Gonzalez, & Mislevy, 2009) due to the lack of reliability of the resulting data. Thus, this study tested the hypothesized model for the five plausible values of science achievement.

Preparation of Data for Analysis

This section describes the process for the preparation of data for analysis. Information about the construction of the dataset is provided first followed by a description of the software used and the sampling weights applied in this study. Next, the procedures for running the confirmatory factor model and the structural equation model are provided along with goodness-of-fit indices for these models.

Construction of analysis dataset. To support and promote secondary analyses aimed at improving science education, the TIMSS 2007 international database makes available the data collected by the project. The dataset for this study was constructed by extracting relevant variables and weights using the IEA International Database Analyzer (IEA IDB Analyzer), which is a plug-in for the IBM Statistical Package for the Social Sciences version 19.0 (SPSS 19.0). The IEA IDB Analyzer generates SPSS syntax that takes into account information from the sampling design in the computation of statistics and their standard errors. In addition, the generated SPSS syntax makes appropriate use of plausible values for calculating estimates of achievement scores and their standard errors. The extracted dataset contained 17 variables and three sampling weights with 7,377 cases.

Applying sample and design weights. An important characteristic of the TIMSS studies, and one that has crucial implications for data analysis, is that data comes from carefully drawn random samples of schools, classes, and students to make inferences about science achievement. For analyses based on these sample data to accurately reflect population attributes, it is necessary that researchers take the design of the sample into

account. This is accomplished by assigning a sample weight to each respondent in the sample and then weighting the respondents by their sampling weight in all analyses. The sampling weights properly account for the sample design, take into account any stratification and disproportional sampling of subgroups, and include adjustments for non-response.

The unit of analysis for this study is only at the student level and a student weight variable TOTWGT was used in the analyses. The use of TOTWGT ensures that the various subgroups that constitute the sample are properly and proportionally represented in the computation of population estimates and that the sample size will be inflated to approximate the size of the population. Additionally, there are weighting variables that identify strata as well as clusters within strata; both (JKZONE and JKREP) were used as part of the identification of the complex sample design programming for use with Mplus.

Software. The software used to analyze the data in this study was SPSS 19.0 and Mplus Version 6.1. SPSS 19.0 was used to generate the correlation matrix as well as the descriptive statistics for the data. Mplus was used for the structural equation modeling (SEM) analyses.

Recoded measures. As described in the measures section, two items were reversed coded. These included one indicator, “science is boring,” (Bore) for the latent factor “intrinsic motivation” and another indicator, “science is not one of my strengths,” (Strength) for the latent factor “perceived competence in science.”

Missing data. The listwise deletion method was selected for this study because it is the simplest and most common method of handling missing data. Also, evidence from various research studies suggested that, in comparison with other methods of handling missing data such as pairwise deletion, listwise deletion tends to produce the least biased estimates (Allison, 2001; Roth, 1994). In a recent study of the impact of missing data in

large-scale assessments, Phan and Kromrey (2006) found that statistical results produced from the listwise deletion method were comparable to those produced by the multiple imputations method, an increasingly promising method of missing data treatment (Byrne, 2001; Kromrey & Hines, 1994; Mullis, 2001; SAS, 2006). All variables in this study had less than 2% missing. Following listwise deletion, 6,946 cases remained from 7,377, a total deletion of 6%. Table 3 provides a summary of estimated means for all values compared with the dataset following listwise deletion.

Table 3

Summary of Estimated Means

	Plan	Conduct	Groups	Bore	Like	Enjoy	Well	Strength	Quick	Gender	Momed	PV 1	PV 2	PV 3	PV 4	PV 5
All	2.59	2.75	2.96	2.70	2.89	2.91	3.19	2.74	2.88	.50	4.30	517.3	517.8	517.3	517.0	517.8
Listwise	2.59	2.75	2.97	2.70	2.89	2.92	3.19	2.75	2.88	.49	4.31	519.2	520.0	519.4	518.9	519.8

Structural Equation Modeling

Structural equation modeling (SEM) is particularly well suited as an analysis technique for this study, due to its ability to include latent constructs and its suitability for use with large samples. Most of the constructs in the proposed study are latent and difficult to measure directly. Given the interest in the hypothesized interrelations of these latent constructs and observed variables, SEM is an appropriate analysis technique because it affords the analysis of a prespecified model with theoretical grounding, which depicts the direction of hypothesized influence.

SEM can be thought of as confirmatory factor analysis (CFA) and multiple regression because SEM is more of a confirmatory technique, but it also can be used for exploratory

purposes. SEM extends to the possibility of relationships among the latent variables and encompasses two steps: (a) a measurement model (essentially the CFA) and (b) a structural model (Schreiber et al., 2006). Two-step modeling is useful in detecting potential model-misspecification and in determining the measurement model invariance (Kline, 2005). In two-step modeling, confirmatory factor analysis of the full measurement model is tested first through freeing the parameters among all constructs and allowing them to correlate; if the fit of CFA of the measurement model is acceptable, then the structural model of the study is tested in the second step.

The structural model comprises the other component in linear structural modeling. The structural model displays the interrelations among latent constructs and observable variables in the proposed model as a succession of structural equations—akin to running several regression equations (Schreiber, Nora, Stage, Barlow, & King, 2006). SEM was conducted using Mplus Version 6.1 with the maximum likelihood estimator (MLR), which is used by Mplus with complex datasets (Muthen & Muthen, 2007, p. 484). The latent constructs were specified as ordered-categorical. The commands for accounting for stratification, cluster, and weight were used by specifying the variable name for each, as is the procedure for Mplus.

Goodness-of-fit indices. The literature suggests the use of more than one fit index to measure goodness of fit to assess a model. Bollen and Long (1993) suggested the inclusion of fit indices that use different assessment techniques, are not sensitive to sample size, and take degrees of freedom (df) into consideration. Reporting fit indices having similar assessment natures does not provide adequate information in evaluating the goodness of fit for a hypothesized model. The fit indices used in the present study were Chi-square

(χ^2), Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Standardized Root Mean Square Residual (SRMR), and Root Mean Square Error Approximation Index (RMSEA).

Chi-square (χ^2) tests the difference between the sample covariance matrix and the restricted covariance matrix, with the assumption that the residual discrepancy between them is equal to zero. According to this index, $p > .05$ indicates a good fit. The higher the probability, the better the chance to obtain a perfect fit. Chi-square, however, may lead to the rejection of reasonable population models because of its sensitivity to large sample sizes (Byrne, 2001). In a recent study, Miles and Shevlin (2007) showed that the χ^2 index is influenced not only by the sample size but also by the reliability of the constructs under investigation. They indicated that higher correlations among observed indicators and accordingly lower unique variance held by each indicator lead to greater model rejection rates in terms of chi-square index because increasing reliability gives greater power to the tested model and causes an increase in chi-square. Therefore, Miles and Shevlin recommended the use of incremental fit indices such as Comparative Fit Index (CFI) and Tucker Lewis Index (TLI) in the interpretation of the chi-square and the model fit.

The CFI compares the hypothesized model with the independence model. The independence model is a highly restricted model in which all variables are considered uncorrelated. The value of CFI ranges from 0 to 1.00. The suggested value for CFI, representative of good fit, is between .95 and 1.00 (Hu & Bentler, 1999). In general, the value of CFI shows consistency with the values of Normed Fit Index (NFI) and Incremental Fit Index (IFI) (Byrne, 2001). Therefore, only CFI was reported in the present study.

Another fit index reported in the current study was Tucker-Lewis Index (TLI). Although TLI, also known as Non-Normed Fit Index (NNFI), is also an incremental fit index similar to CFI, it considers and balances the effect of model complexity (Hu & Bentler,

1999). Model complexity is especially important in the assessment of simpler models with total observed variables equal or less than 10 (Kline, 2005). Because RMSEA is reported to be sensitive to model complexity (Kenny & McCoach, 2003), the report of TLI gains significance. A TLI value close or above .95 is considered acceptable with large sample sizes (Hu & Bentler, 1999).

The Standardized Root Mean Square Residual (SRMR) is based on transforming both the sample covariance matrix and the predicted covariance matrix into correlation matrices. The SRMR is thus a measure of the mean absolute correlation residual, the overall difference between the observed and predicted correlations. Values of the SRMR less than .08 are generally considered favorable (Kline, 2005).

The last index employed in testing model fit was Root Mean Square Error Approximation (RMSEA), considered one of the most efficient indexes available (Byrne, 2001). RMSEA calculates the discrepancy between the population covariance matrix, as if it were known, and the restricted model covariance matrix and then estimates the potential error (Browne & Cudeck, 1993). Reported by Byrne (2001), RMSEA values of less than .05 indicate good fit, between .05 and .08 represent reasonable fit, between .08 and .10 indicate mediocre fit, and values greater than .10 represent poor fit (Hu & Bentler (1999). The null hypothesis is that the RMSEA is .05, a close-fitting model. The p value examines the alternative hypothesis that the RMSEA is greater than .05. So if the p is greater than .05, then it is concluded that the fit of the model is "close." MacCallum, Browne, and Sugawara (1996) suggested that RMSEA value should be reported with its 90% confidence intervals, in order to make a better assessment of its adequacy. Because RMSEA is affected by χ^2 , the limitations mentioned regarding the χ^2 statistics also affect the outcome of RMSEA; essentially increasing the reliability of measured indicators may lead to higher RMSEA

resulting in the rejection of a true population model (Miles & Shevlin, 2007). The goodness of fit resulting from the interpretation of RMSEA may suggest different action in comparison to the fit resulting from the interpretations of CFI and TLI because these fit indices may provide conflicting explanations in the case of model complexity (Kenny & McCoach, 2003). Therefore, extra caution was given during the interpretation of the results.

A determination as to whether a good model fit existed was based upon assessing the totality of the evidence provided by the goodness-of-fit indices, as well as on an examination of the parameter estimates for their significance. Because structural equation modeling (SEM) includes paths among latent constructs with hypothesized directional influence, which CFA does not, the paths also were examined for their significance.

This study tested five separate models for each plausible value outcome variable. The models were identical with the exception of the plausible value outcome variable. A model depicting the structural model for the outcome variable is shown in Chapter 4, Figure 3. The full model depicting both the structural and measurement model is shown in Chapter 2, Figure 2.

Summary

This chapter provided descriptions of the Third International Mathematics and Science Study, participants, and the measures used for the analyses. Additionally, this chapter explained the preparation of the data for analysis, including how the dataset was constructed. The procedures for conducting the structural equation model also were presented. Chapter 4 provides the results of the study.

IV. Results

The purpose of this study was to examine associations among students' perceptions of autonomy support and its relationship to students' intrinsic motivation, perceived competence in science, and science achievement. The sample for this study included the 6,946 eighth-grade students who participated in the TIMSS 2007 study in the United States. The sample included 13- and 14-year-old students from 239 schools across the United States. The demographics of this sample were reported in Chapter 3 (pp. 26-27). This chapter shares the results from the descriptive and structural equation modeling analyses (SEM). First, the descriptive analyses and correlation table for model variables are presented. Second, the validity, reliability, and confirmatory factor analysis of the measurement model are discussed. Finally, the structural equation modeling results for the hypothesized model are provided.

Descriptive Statistics and the Correlation Matrix

SPSS 19.0 was used to generate the correlation matrix and descriptive statistics. The dataset of eighth-grade students ($n = 6,946$) in the United States who participated in the Trends in International Mathematics and Science Study (TIMSS 2007) was used for these analyses. Analyses included screening the data to assess normality and outliers.

Table 4 reports the correlations among all study variables as well as their minimums, maximums, means, standard deviations, skewness, and kurtosis. All Pearson-product correlations were statistically significant ($p \leq 0.001$) except between Plan and Mother's education ($p = 0.479$), Conduct and Gender ($p = 0.411$), and Groups and Gender ($p = 0.019$).

Multicollinearity was assessed by examining the correlations among the variables, none of which reached 0.85 or higher (Kline, 2005, p. 56).

Table 4

Correlations and Descriptive Statistics of the Variables in Hypothesized Model

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Plan	-															
2. Conduct	.68	-														
3. Groups	.50	.62	-													
4. Bore	.11	.13	.09	-												
5. Like	.16	.18	.14	.63	-											
6. Enjoy	.18	.18	.14	.60	.81	-										
7. Well	.12	.15	.13	.38	.57	.54	-									
8. Strength	.03	.06	.05	.43	.46	.43	.55	-								
9. Quickly	.15	.16	.13	.39	.58	.57	.65	.52	-							
10. Gender	.04	.01	-.04	.03	.07	.07	.06	.08	.09	-						
11. Momed	-.04	.02	.01	.01	.02	.00	.02	.02	.01	-.01	-					
12. Value 1	-.06	.07	.07	.14	.21	.17	.30	.29	.27	.08	.15	-				
13. Value 2	-.07	.06	.05	.14	.21	.17	.30	.29	.27	.09	.15	.90	-			
14. Value 3	-.06	.06	.06	.14	.21	.17	.30	.28	.27	.09	.15	.89	.89	-		
15. Value 4	-.07	.06	.05	.14	.21	.17	.30	.28	.27	.09	.15	.90	.89	.89	-	
16. Value 5	-.07	.06	.06	.15	.22	.18	.30	.28	.26	.09	.15	.90	.89	.89	.90	-
Minimum	1	1	1	1	1	1	1	1	1	0	1	227.3	233.1	194.5	264.2	229.2
Maximum	4	4	4	4	4	4	4	4	4	1	7	763.6	778.7	786.5	763.3	771.7
Mean	2.59	2.75	2.96	2.71	2.89	2.91	3.19	2.75	2.88	.49	4.31	519.2	520.0	519.4	518.9	519.8
SD	.97	.94	.94	1.1	1.0	.99	.84	1.1	.94	.500	1.69	82.78	81.95	82.35	82.93	82.68
Skewness	.01	-.10	-.40	-.23	-.55	-.56	-.90	-.29	-.40	.03	.10	-.17	-.17	-.20	-.18	-.17
Kurtosis	-1.02	-1.02	-.94	-1.21	-.86	-.73	.28	-1.16	-.80	-2.00	-1.06	-.24	-.25	-.17	-.27	-.24

As explained in Chapter 3, the science achievement score used in this study was based on five plausible values whereby five separate estimates of each student's score were generated on each scale, based on the student's responses to the items in the student's booklet and on the student's background characteristics (Olson et al., 2008). The descriptive statistics for these five variables also are reported in Table 4.

Validity and Reliability of Measurement Model

As the first step of two-step modeling, the structural model was respecified as a measurement model and was tested for its adequacy. The measurement model depicts the pattern of observed variables for the latent constructs in the hypothesized model. A major component of the measurement model is to test the reliability of the observed variables. This approach was adopted because Marsh and his colleagues (1998) recommended that researchers use all items as measured indicators for the measurement of latent constructs to obtain more powerful and accurate estimates and proper solutions. For the assessment of the measurement model, all latent constructs were allowed to intercorrelate. The full measurement model provided an adequate fit to the data $\chi^2 [df = 24, N = 6946] = 289.61, p < .001$; RMSEA = .04 (90% CI (.04, .04)); CFI = .99; TLI = .98; and SRMR = 0.02. The χ^2 was significant, but it was sensitive to large sample sizes (Byrne, 2001). RMSEA values less than .05 indicate good fit (Byrne, 2001). The suggested value for CFI and TLI, representative of good fit, is greater than .95 (Hu & Bentler, 1999). Values of the SRMR of less than .10 are generally considered favorable (Kline, 2005).

Factor loadings, measurement error variances, standardized error variances (delta), average variances extracted, and construct reliabilities are provided in Table 5. The evaluation of the factor loadings in Table 5 shows the results from the analysis of the eighth-grade indices. The three latent factors for science at the eighth grade—autonomy support

(AS), intrinsic motivation (IM), and perceived competence in science (PCIS—were based on nine observed component variables. The evaluation of the factor loadings showed that the observed indicators had high factor loadings with their common factors with only one just below .70 indicating that they adequately reflected their underlying latent variables. All indicators in the model had statistically significant factor loadings ($p < .001$), supporting the existence of significant associations among measured indicators and their latent constructs. Further, the analysis of the squared multiple correlations (item reliabilities in Table 5) demonstrated that all the items in this study met the recommended criterion of .40 (Bollen, 1989).

Table 5

CFA Standardized Factor Loadings, Reliability Estimates, and Average Variances

	AS		IM		PCIS		Item Reliabilities	Delta
	Load	SE	Load	SE	Load	SE		
Plan	.74	.01	-	-	-	-	.55	.45
Conduct	.91	.01	-	-	-	-	.82	.18
Groups	.68	.01	-	-	-	-	.47	.53
Enjoy	-	-	.87	.01	-	-	.76	.24
Bore	-	-	.67	.01	-	-	.44	.56
Like	-	-	.92	.01	-	-	.85	.16
Well	-	-	-	-	.81	.01	.66	.34
Quick	-	-	-	-	.79	.01	.63	.37
Strength	-	-	-	-	.67	.01	.45	.55

Variance extracted, construct reliability, and intercorrelations among latent variables are presented in Table 6. The average variance extracted indicates what percentage of the

variance of the construct an individual item explains. Fornell and Larcker (1981) recommend a benchmark of .50 or higher for average extracted variance. The average variance extracted for each latent factor exceeded .50 and the construct reliability estimates all equaled or exceeded .80 (Table 6). Therefore, all the indicator items are retained and adequate evidence of convergent validity is provided. Latent factor correlations confirmed that all bivariate correlations were statistically significant ($p < .001$) and in the expected directions, providing preliminary support for the hypothesized model. The techniques for evaluating CFA as outlined by Brown (2006) were met and the literature supports these indicators as influential to the outcomes of this study.

Table 6

Variance Extracted, Construct Reliability, and Intercorrelations among Latent Variables

	AS	IM	PCIS
Variance Extracted	61.3%	68.3%	58.0%
Construct Reliability	0.82	0.86	0.80
<i>Latent Variables Intercorrelations</i>			
Autonomy Support (AS)	1.0		
Intrinsic Motivation (IM)	.15	1.0	
Perceived Competence in Science (PCIS)	.19	.77	1.0

The three component variables for autonomy support formed a highly reliable scale with a reliability coefficient, Cronbach's alpha, of .82 for science in the United States at the eighth-grade level. The three component variables for intrinsic motivation formed a highly reliable scale with a Cronbach's alpha of .86 for science in the United States at the eighth-grade level. The three component variables for perceived competence in science form a

highly reliable scale with a Cronbach's alpha of .80 for science in the United States at the eighth-grade level.

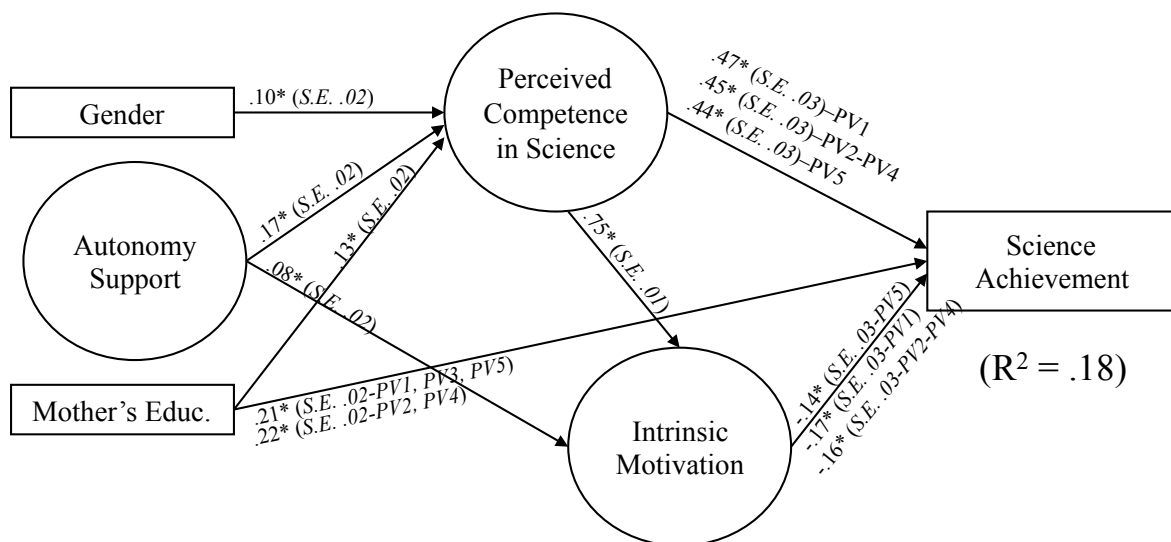
SEM Analyses for Science Achievement

Following the analyses of the measurement model and the CFA, SEM analyses were conducted on the model that examined the relations among motivational factors for science achievement. Mplus 6.1 was used for the analyses.

Analysis of the parameter estimates revealed that the following two paths in the full model were not significant: gender to science achievement and perceived autonomy support to science achievement. Model results from the chi-square (χ^2) and goodness-of-fit indices were: $\chi^2 [df = 45, N = 6946] = 569.88, p < .001$; RMSEA = .04 (90% CI (.04, .04)); CFI = .98; TLI = .97; and SRMR = 0.02. Though the goodness-of-fit indices provided values within an acceptable range, the non-significant paths were removed, and a revised model (as depicted with findings in Figure 3) was fit to the data.

Figure 3

Final Revised Structural Model for Science Achievement



Note. * $p \leq .001$; **, PV = plausible value; paths are reported as standardized estimates (stdyx)

The revised structural model results, as reported in Figure 3, indicated that the revised model provided a good fit to the data (Table 7). The χ^2 was significant, but it was sensitive to large sample sizes (Byrne, 2001). RMSEA values of less than .05 indicate good fit (Byrne, 2001). The suggested value for CFI and TLI, representative of good fit, is greater than .95 (Hu & Bentler, 1999). Values of the SRMR less than .10 are generally considered favorable (Kline, 2005). Because the overall fit of the model was considered adequate, the structural relations in the model were interpreted.

Table 7

Fit Indices for Hypothesized Model for Each Plausible Value

Model	χ^2	RMSEA	CFI	TLI	SRMR
Model w/ PV1	569.74*	.04	.98	.97	.03
Model w/ PV2	592.61*	.04	.98	.97	.03
Model w/ PV3	573.75*	.04	.98	.97	.02
Model w/ PV4	588.90*	.04	.98	.97	.03
Model w/ PV5	599.83*	.04	.97	.96	.03

Note. *Each value is significant at the $p < .001$; $df = 48$; PV = plausible value

All paths were significant at the $p < .001$ level. The three direct effects on science achievement were from perceived competence in science, mother's education, and intrinsic motivation. The strongest direct effect was that of perceived competence in science ($\beta = .44$). Mother's education also exerted substantial direct effect on science achievement of .21. Intrinsic motivation's direct effect ($\beta = -0.16$) on science achievement was significant but surprisingly was not in the expected direction. There were four indirect effects on science

achievement—autonomy support, perceived competence in science, gender, and mother’s education (Table 8).

Table 8

Direct, Indirect, and Total Effects on Science Achievement

Independent Variable	Perceived Comp Science			Intrinsic Motivation			Science Achievement			
	Effect	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
AS		.17*		.17*	.08*	.13*	.21*		.04*	.04*
PCIS					.75*		.75*	.45*	-.12*	.33*
IM								-.16*		-.16*
Gender		.10*		.10*		.08*	.08*		.03*	.03*
Mother’s Education		.13*		.13*		.10*	.10*	.21*	-.02*	.19*

*p < .001

The strongest total effect in the model was that of perceived competence in science ($\beta = .33$), followed by mother’s education with .19 and intrinsic motivation ($\beta = -.16$).

Autonomy support ($\beta = .04$) and gender with .03 had small total effects compared to the other variables in the model.

Three factors were proposed to have significant direct effects on perceived competence in science, including gender, autonomy support, and mother’s education.

Autonomy support had the largest direct effect on perceived competence in science ($\gamma = .17$), followed by mother’s education and gender, .13 and .10 respectively.

Two factors were proposed to have direct significant effects on intrinsic motivation, including perceived competence and autonomy support. Perceived competence in science has a strong direct effect on intrinsic motivation ($\beta = .75$), and autonomy support had a much

weaker direct effect on intrinsic motivation ($\gamma = .08$); however, autonomy support's total effect on intrinsic motivation was .21. Gender had an indirect effect of .08 on intrinsic motivation, and mother's education also had an indirect effect of .10 on intrinsic motivation.

Summary

This chapter presented the results of the descriptive and structural equation modeling analyses (SEM) for this study. The descriptive statistics and correlation table for the hypothesized model variables were given. The validity, reliability, and confirmatory factor analysis of the measurement model were discussed. Finally, the structural equation modeling results for the hypothesized model were provided.

V. Discussion

Using a sample of 6,946 eighth-grade students who participated in the TIMSS 2007 study in the United States, this study examined a structural motivation model for science achievement based on the integration of Deci and Ryan's Self Determination Theory (1985, 1991). The findings of the current study extend our knowledge in understanding the role of basic needs on students' motivational and academic outcomes in science classrooms. The structural model (Figure 3), which adequately fit the sample data of this study, explained approximately 18% of the variance among students' science achievement. This chapter first briefly discusses the current state of science education in the United States. Next, the associations among autonomy support, perceived competence in science, intrinsic motivation, and science achievement are examined in light of the research questions and hypotheses. The final section includes implications of the study's findings for future research, an acknowledgement of study limitations, and a brief conclusion.

Current State of Science Education

Science proficiency serves as an important gateway for educational and career opportunities. The TIMSS 2007 results show that only 10% of U.S. eighth graders are performing at or above an advanced level in science. By 12th grade, only 1% performs at or above the advanced level (TIMSS, 2007). These proficiency rates create serious consequences for higher education. The National Science Board (2010) found that only about a third of bachelor's degrees earned in the United States are in fields related to science, technology, engineering, and mathematics, compared with approximately 53% of first

university degrees earned in China, and 63% of those earned in Japan. More than half of the science and engineering graduate students in U.S. universities are from outside the United States. Moreover, the TIMSS 2007 results illuminate the persistent science achievement gap that leads to the current crisis of the gross underrepresentation of minority groups, economically disadvantaged groups, and women in science, technology, engineering and mathematical fields. The United States must do a better job of educating all young people to compete in an increasingly high-tech global economy.

The purpose of this study was to test a motivational model of achievement in science education. The model suggests that students' perceptions of autonomy support would influence students' intrinsic motivation and perceived competence in science. In turn, these self-perceptions were hypothesized to influence students' science achievement. The results from the structural equation modeling (SEM) analyses provided mixed support for the proposed model.

Perceptions of Autonomy Support, Perceived Competence in Science, and Intrinsic Motivation

The first research question in this study asked if the hypothesized model (Figure 2, p. 21) fit the sample data used in this study using the goodness-of-fit indices. The structural model explained approximately 18% of the variance among students' science achievement and adequately fit the sample data.

The next two research questions asked whether perceived autonomy support in the classroom significantly related to students' perceived competence in science and intrinsic motivation. Consistent with self-determination theory and the hypotheses, this study found that students' perceptions of autonomy support had a positive and significant relation to perceived competence in science and intrinsic motivation. These findings are consistent with

other studies that have shown students in classrooms with autonomy-supportive teachers, as compared with classrooms with controlling teachers, are likely to show greater perceived academic competence (Deci, Schwartz, Sheinman, & Ryan, 1981; Kage & Namiki, 1990; Ryan & Grolnick, 1986) and higher academic intrinsic motivation (Deci, Nezlek, & Sheinman, 1981; Miserandino, 1996). Using a sample of elementary students, Deci et al. (1981) found that teachers categorized as autonomy supporting had students who scored high on intrinsic motivation, perceived competence, and self-esteem. The findings of this study indicated that the relation between autonomy support and student motivation found for elementary-aged students (Deci et al., 1981) are similar for older, middle school-aged students.

These findings are important because prior research has shown competency-related beliefs to decline during adolescence (for reviews, see Anderman & Maehr, 1994; Eccles, Wigfield, & Schiefele, 1998). Specifically, adolescents have lower perceptions of their competence for different school subjects and other activities than do their younger peers (Eccles, Wigfield, Flanagan, Miller, Reuman, & Yee, 1989; Jacobs, Lanca, Osgood, Eccles, & Wigfield, 2002; Marsh 1989; Wigfield, Eccles, Mac Iver, Reuman, & Midley, 1991). Researchers also have found decreases in children's intrinsic motivation to learn, in both cross-sectional and longitudinal studies (Gottfried, Fleming, Gottfried, 2001; Harter, 1981). Harter measured intrinsic motivation generally, and Gottfried et al. (2001) measured intrinsic motivation for different subject areas (math, reading, social studies, science), as well as general school intrinsic motivation. Gottfried et al. (2001) found declines across ages 9 - 16 in all these aspects of intrinsic motivation except social studies.

This study underscores the importance of tending to students' perceptions of autonomy in science classrooms. Students who feel autonomous will have higher levels of

competence and intrinsic motivation, which is critical during adolescence and in science education. Most of the recommendations suggested by reforms in science education (NRC, 1996) support the vision of science classrooms where students are autonomous and teachers guide rather than control the learning process. Guay, Boggiano, and Vallerand (2001) tested three models in regard to the linkages among autonomy support, intrinsic motivation, and perceived competence and found that autonomy-supportive teachers produced an increase in perceived competence that, in turn, increased students' intrinsic motivation. Students are to abandon passive-uptake roles and become more actively engaged in the learning process. Adopting an instructional model that gives students a full sense of volition and choice could influence students toward greater perceived competence and develop more intrinsic motivation necessary for persistence and success in science.

Perceptions of Autonomy Support and Science Achievement

The fourth research question asked whether perceived autonomy support in the classroom significantly related to science achievement. This study found that students' perceptions of autonomy support were not significantly related to science achievement not supporting the stated hypothesis. However, these results should be interpreted with caution. The construct of autonomy support in this study was based on items that were assumed to measure the latent construct of autonomy but may not be completely consistent with the nature of self-determination theory as defined by Deci and Ryan (1985).

The measurement of autonomy must be fundamentally about a student's sense of being the author and origin of one's behavior (de Charms, 1968). As such, teacher-provided autonomy support is fundamentally the interpersonal behavior that teachers provide during instruction to identify, nurture, and build students' inner motivational resources (Deci & Ryan, 1985; Reeve, Deci, & Ryan, 2004). The indicators for the latent construct of

autonomy support may have tapped students' perceptions of autonomous-type teaching practices but may not have tapped whether students perceived their teachers as autonomy supporting. Instructional strategies such as planning and conducting experiments and working in groups may appear to support autonomy, and were the best indicators from the student questionnaires to get at students' perceptions of autonomy support in the classroom, but unless students are able to experience a sense of choice while carrying out these activities, they still could experience them as controlling. In other words, just providing more opportunities for students to be engaged in student-centered, autonomy-supportive type activities does not necessarily translate to students perceiving themselves as being responsible for the initiation of the activities.

An alternative explanation may be that the benefits of autonomy-supportive techniques may not be captured in large-scale assessments like TIMSS. In autonomy-supportive environments, students conduct and plan experiments, write research papers, work in groups, participate in scientific inquiry, and engage in higher level thinking skills. Standardized paper-and-pencil, multiple-choice tests may not do a good job measuring this type of learning. Shifting to a more autonomous inquiry-based structure in classrooms is antithetical to controlling systems that use tests to drive curriculum. As a result, it is possible that students who experienced more autonomy-supportive teachers did develop better skills to truly apply scientific inquiry to real world problems, but those skills may not apply to multiple-choice tests. Unfortunately, this dataset has no way to test this possibility.

Perceived Competence in Science and Science Achievement

The fifth research question asked whether perceived competence in science significantly related to science achievement. Compared to the other predictors in the model, perceived competence in science had a strong relation to science achievement supporting the

stated hypothesis. Because motivational beliefs mediate the effects of prior achievement, knowledge, and skills on subsequent achievement (Schunk, 1985), science competency beliefs often are excellent predictors of academic achievement (Bandura, 1986). This result also shows agreement with the literature. Shen (2002) and Shen and Pedulla (2000) noted positive relations between science achievement and self-perceptions. Other research (Britner, 2008; Caprara et al. 2008; House, 2008; Lavonen & Laaksonen, 2009) also confirms the positive relation between students' more positive perceptions of their ability to learn science and higher achievement in science.

There is a strong emphasis in education, educational psychology, and other fields on the study of the self. This emphasis is grounded on the assumption that individuals' perceptions of themselves and their capabilities are vital forces in their success or failure in achievement settings. Along with this increasing emphasis on the study of self are ever-increasing conceptualizations of competence beliefs. These include self-efficacy, perceived competence, task-specific self-concept, self-concept of ability, academic self-concept, perceptions of task difficulty, self-perceptions of ability, self-appraisals of ability, subjective competence, and self-confidence.

Perceived competence in science, as defined in this study, is more closely related to academic self-concept than to self-efficacy. Bong and Skaalvik (2003) stated that academic self-concept primarily indicated one's self-perceived *ability* within a given academic area (e.g. science), while academic self-efficacy primarily indicated one's self-perceived *confidence* to successfully perform a particular academic task. Their argument is based upon the comparison of typical items measuring both constructs. Academic self-efficacy items (Pajares, Miller, & Johnson, 1999) usually start with "how confident are you..." (e.g. "that you can successfully solve equations containing decimals"). In contrast, self-concept items

such as “I have always been good at science” are clearly more aimed at measuring students’ self-perceived academic ability. As such, for this study, perceived competence in science is similar to the construct of academic self-concept.

Despite the difference between the concepts of self, available research links both academic self-concept and academic self-efficacy to a number of desired outcomes such as persistence (Lent, Brown, & Larkin, 1986; Skinner, Wellborn & Connell, 1990), intrinsic motivation (Bandura, 1997; Skaalvik, 1997), and academic achievement (Marsh & Yeung, 1997; Pintrich & Schunk, 2002). Hence, Bong and Skaalvik (2003) conclude that academic self-concept and academic self-efficacy seem to have comparable relations to students’ motivation, emotion and achievement. This study lends further support to extant research on self-beliefs and their importance to academic achievement contexts.

Intrinsic Motivation and Science Achievement

The final research question asked whether students with higher intrinsic motivation would have higher science achievement. Intrinsic motivation to learn science—interest in and enjoyment of science—was found to have a slightly negative relation to science achievement in this model rejecting the hypothesis. This finding was unexpected based on prior research. However, an analysis of the TIMSS 2007 data shows nations that have the highest average science scores (Korea, Japan, Hong Kong, Taiwan) also have the lowest percentage of students with high science intrinsic motivation. The United States may be doing a commendable job of encouraging students to like science, but are seemingly not doing as well at educating students to learn science. Nations such as Korea and Japan may be doing a better job of teaching students science, but are not doing a commendable job of encouraging students to enjoy science. Science educators in the United States must work to find the appropriate balance of sustaining students’ intrinsic motivation in learning science

while at the same time teaching in a way that increases students' science achievement. It is also important to consider learner outcomes as multifaceted. The goals of science education should include not only content, conceptual, and procedural knowledge but also the motivation to inspire students to be lifelong learners.

Plausible Values

This study tested the hypothesized model with each of the five plausible values of science achievement. Previous work has shown that using a single plausible value ignores the uncertainty associated with the measurement of proficiency distributions and the standard errors for statistics of interests are generally underestimated. However, in this study, the efficacy of running the model five different times for each value was called into question. Identical results for all statistics of interest for this study were identical for each of the five plausible values.

Implications of the Study

Science education reform efforts have actively recommended using inquiry-based instruction to engage students in learning science (NRC, 1996). Past research has shown that inquiry-based science instruction correlates with an increase in achievement (Freedman, 1997; Johnson, Kahle, & Fargo, 2007; Kahle, Meece, & Scantlebury, 2000; Mattern & Schau, 2002; McReary, Golde, & Koeske, 2006; Morrell & Lederman, 1998; Oliver-Hoyo & Allen 2005; Parker & Gerber, 2000). A major focus of reform efforts in science education is to help science teachers depart from traditional, didactic methods of instruction and to provide opportunities for students to become engaged in more autonomous, active, and self-directed learning.

Although the ideas of inquiry science have been widely accepted since the publication of the *National Science Education Standards* (1996), fundamental changes in instructional

practices have been slow in coming. Studies of teaching and learning in science classrooms report that most teachers are still using traditional, didactic methods (Seymour, 2002; Unal & Akpinar, 2006). In 2000, the National Research Council recognized this and released *Inquiry and the National Science Education Standards*, which presented research that science educators were unclear about what inquiry meant and uncertain about implementing inquiry-based instruction. In 2006, Kirschner, Sweller, and Clark argued that inquiry-based instruction did not work. However, Hmelo-Silver, Duncan, and Chinn (2007) argued that Kirschner and colleagues loosely defined inquiry and problem-based learning as minimally guided instruction and used a flawed evidentiary base to support their conclusion.

Inquiry learning as described by the reform documents places autonomy at the center of change. Certainly, though, this autonomous learning is not akin to minimally guided learning. Inquiry and autonomy-supportive teaching in no way suggests that learning takes place independently of the teacher (though of course it may); what it does suggest is that the teachers may need to refocus their teaching, supporting the development of the learner's autonomy. Autonomous learning must involve a capacity for taking control, a knowledge of how to learn as well as the motivation to learn. Self-determination theory provides a rationale behind inquiry and takes the focus away from teachers executing hands-on activities and experiments to taking the student's perspective, acknowledging the student's feelings and perceptions, providing choice, and giving opportunities for initiative. As argued earlier, a classroom may look reformed, but students in the classroom may be deficient in having their needs for autonomy and competence satisfied.

Deci (1995) described autonomy as acting volitionally with a sense of choice and a willingness to behave responsibly in accordance with one's interests and values. A key aspect of Deci's definition was the importance of choice: "Providing choice, in the broad

sense of the term, is a central feature in supporting a person's autonomy" (1995, p. 34). Deci recognized the fundamental drive of children to make sense of their world. Deci said "a child's curiosity is an astonishing source of energy" (1995, p. 18). Reform curricula in science have sought to tap into this reservoir of natural curiosity by utilizing inquiry-based approaches to instruction. But for inquiry science to succeed, teachers must recognize the connections between inquiry and autonomy. Inquiry can be encouraged, stimulated, and aroused, but it cannot be forced because it is a volitional activity.

For inquiry to occur, students first must have the opportunity to choose to engage in it. Then they must also have the capacity to take the relevant factors into account in making the necessary decisions for enacting the inquiry. The conditions that support students' perceptions of autonomy, opportunities to make choices and to work cooperatively with others, also support inquiry and have been shown to increase perceived competence in science and intrinsic motivation in this study. These findings provide some insight into how science educators may begin to increase science achievement and interest of students. In particular, the present results suggest that teachers should seek to foster an autonomy-supportive climate to foster positive science competence, which significantly and uniquely affects science achievement, and intrinsic motivation which is critical to persistence in science.

A controlling orientation to teaching is often the default motivating style for science instruction in K-12 classrooms. Current research in the field of motivation is focusing on helping teachers become more autonomy supportive toward students. Intervention research shows that teachers can learn how to become more autonomy supportive toward students, and this has been shown to be true for inexperienced preservice teachers (Reeve, 1998), experienced middle-school teachers (de Charms, 1976), and experienced high school teachers

(Reeve, Jang, Carrell, Barch, & Jeon, 2004). Learning to become more autonomy supportive seems to revolve around accomplishing three key tasks with teachers: 1. Making teachers aware of why they are often controlling and helping them become less controlling; 2. Educating teachers on the benefits of an autonomy-supportive teaching style; and 3. Developing the interpersonal skills and acts of instruction that actualize an autonomy-supportive style.

Reeve and Halusic (2009) provide various instructional behaviors that provide a possible framework for enacting an autonomy-supportive approach to instruction. These instructional behaviors help teachers anticipate some common classroom events that have motivational implications—helping students start a learning activity, supporting students’ ongoing engagement, conversing and interacting with students as learners, helping students profit from their time with learning materials, and encouraging confused and frustrated learners. This work switches the focus from understanding the problem of controlling instructional practices to offering a solution for remedying it. Future research must focus on helping teachers become more autonomy supportive and the work of Reeve and his colleagues offers practical steps to encourage teachers to support students’ autonomy.

Limitations

Using a large database such as TIMSS does have limitations. This study is a secondary analysis and the data for TIMSS 2007 was collected for a different purpose than for the purpose of this study. The data from students were limited by the questions asked, the directions for those questions, and the response selections provided.

The Likert-type scales used in the TIMSS study is one of the limitations because they are based on four point scales for measuring the indicators of the three latent constructs. In most cases, methodologists simply use a rule of thumb that there must be a certain minimum

number of classes in the ordinal independent. Most agree that five or fewer is inappropriate; others have insisted on 7 or more. However, it must be noted that use of four–point Likert scales for independent variables in regression is not unusual in the literature.

Another limitation is this study’s dependence on self-report measures from students. There is a possibility of inflated correlations when variables are measured at the same time from the same participants. Although self-reports are valid measures of subjective psychological constructs such as motivation and self-beliefs, the results of the present study would be much stronger if measures other than self-reports were included. For example, the measure autonomy support would be strengthened if other measures were included. Other measures might include student interviews or observations of lessons. These measures would provide relevant information about autonomy-supportive techniques used by teachers and further knowledge on student thinking which would complement student self-reports. Such measures also support multi-level modeling which is the best approach to address school and classroom influences on individuals. Different measures have their own strengths and limitations, and researchers are recommended to use different methodologies in conjunction to collect converging evidence.

Finally, the present study is a correlational study using survey data. Because of this limitation, causal relations between variables cannot be asserted. For example, the analysis of this structural equation model supported an interpretation in which perceived competence in science was partially mediating the effect of perceived autonomy support on intrinsic motivation. This result indicates that the student perception of autonomy support predicted student intrinsic motivation. Nevertheless, it is equally plausible to say that intrinsic motivation predicted students’ perceptions of autonomy support. In other words, students who are highly intrinsically motivated may perceive teachers as more autonomy supportive

than less intrinsically motivated students. Because the student self-report data of the present study were correlational, it is possible that students who were more intrinsically motivated perceived their teachers as being more supportive to their competence and autonomy than students who were less intrinsically motivated.

Conclusion

The purpose of this study was to examine associations among students' perceptions of autonomy support and its relationship to students' intrinsic motivation, perceived competence in science, and science achievement using a sample of 6,946 eighth-grade students who participated in the TIMSS 2007 study in the United States. Self-determination theory was used as a guiding theoretical foundation and a structural model was tested to examine the relations among motivational factors for science achievement.

The study demonstrated that perceived competence in science was significantly and positively related to science achievement. Students' perceptions of autonomy support were positively related to students' perceived competence in science and intrinsic motivation. Intrinsic motivation was related negatively to science achievement (though the effect was relatively small). The present study suggests one possible way to improve science instruction and achievement and offers a motivational model for understanding and analyzing reform-based inquiry instruction in science classrooms.

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