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Project STIMMULIS: Science Teachers Integrating Mathematical Modeling for Undergraduate Learning and Instruction in Schools

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Abstract: Computer-based mathematical modeling in Physics is a process of constructing models of concepts and the relationships between them in the scientific characteristics of work. In this manner, computer-based modeling integrates the interactions of natural phenomenon through the use of models, which provide structure for theories and a base for experimentation. Utilizing this method, scientists construct knowledge, and in like manner, students in science construct their understandings in significant ways, addressing their preconceptions and their knowledge of concepts in physics. Project STIMMULIS provides a mathematical modeling context for pre-service mathematics and science teachers' conceptual and applied understanding of motion. Project STIMMULIS can serve as a prototype for teacher education departments by (1) providing rich science and mathematics content through a scientific and mathematical modeling based curriculum, and (2) developing, implementing, and demonstrating innovative constructivist practices (strategies) for teaching science and mathematics.

Rationale

El Paso is a bicultural, bilingual community with a 76.6% Hispanic population. Combining El Paso's population with that of its sister city, Ciudad Juárez, Mexico, our community is the largest metropolitan area on any international border in the world. Students at the University of Texas at El Paso (UTEP) are mostly female, and 50% of the total student population is made up of first-generation college students. These demographics are accompanied by low socioeconomic and educational factors: 23.6% of local families live below the poverty level, compared to 12.5% nationally; 32.9% of 25 year-olds have not graduated from high school; 19% of local residents have less than a ninth grade education with only 15.8% holding a bachelor's degree or higher. Due to its location and quality of its academic programs, the University of Texas at El Paso (UTEP), ranked among top four-year colleges by enrollment and degrees to Hispanics (*Hispanic Outlook in Higher Education*, 2006), and the surrounding community are in a unique position to contribute to the development of future Hispanic scientists, mathematicians, engineers, and health professionals.

We are in dire need of addressing the lack of student achievement in mastering fundamental science and mathematics knowledge. In the NAEP data for 2005 for science at the national level, there was no significant change in the gap between White and Hispanic achievement for grades 4 and 8, with the score gap being 32 points. In science at the state level for 8th grade, students scored poorly on Objective III, Structure of Matter (scoring 62%), and Objective IV, Motion, Force and Energy (scoring 63%). When the state test, the Texas Assessment of Knowledge and Skills (TAKS), science data were disaggregated, only 61% of Hispanic students met the standard. In Texas, on the Nations Report Card for 2005, 47% of 8th grade students scored below basic level in science, and only 21% were considered proficient.

On the Nation's Report Card for mathematics published in 2005, in Texas, 28% of 8th grade students scored below the basic level of the NAEP assessment with an average score gap of 29.25, with only 25% scoring at the proficient level. On the mathematics TAKS test administered to 5th – 8th grade students, the topics they scored poorly on were geometry and spatial reasoning objectives, with only 54% of 7th grade students answering correctly on these objectives, and only 45% of 8th grade students answering correctly on objectives related to mathematical processes (patterns, relationships, and algebraic thinking).

Based on our state certification test, the Texas Examinations of Educator Standards (TExES), results from 2007, our pre-service teachers earning a 4-8 science/math certification performed poorly on key competencies including transformational geometry (Geometry and Measurement Domain), mathematical connections within and outside mathematics (Mathematical Processes Domain), number theory (Number Concepts Domain), and properties of matter (Physical Science Domain). Similarly, our pre-service teachers earning a 4-8 generalist certification performed poorly in the general mathematics domain on the following competencies: number theory, linear functions, foundations of calculus, measurement, transformational geometry, and problem solving.

As one of the 11 institutions participating in *Teachers for a New Era* grant sponsored by the Carnegie Foundation, we have a critical stake in teacher training. The relationship between our university and the local public school districts is often viewed as a "closed loop" since 70% of teachers currently working in local school districts are themselves graduates of local schools and hold education degrees or certification from our university. According to the National Science Board (2006), educators need to learn effective pedagogical techniques to reach English Language Learners (ELLs). To increase the achievement level of all students, they need opportunities to learn science and math that focus on critical reasoning skills. The Board emphasized that these opportunities must occur at an early age. Our project provides intellectual resources to improve science and mathematical reasoning and establishes a relationship between scientific practice and sense-making through modeling (Brown, 1992; Lehrer & Schauble, 2000).

A major challenge for science and math teachers is to instruct students who come with diverse cultural and linguistic backgrounds. Often, they instruct their students from a mainstream perspective, not recognizing that students bring with them a rich set of linguistic and cultural resources that can enhance their science and math learning (Lee, 2002; 2003; 2005; Rosebery, Warren, & Conant, 1992). Based on the knowledge that there is limited attention given to science and math instruction within an English language and literacy development context (Lee, 2005), an important goal of our project is to establish a set of authentic learning experiences for future teachers to better serve their future ELL students.

Key Components of Project STIMMULIS

The key components of our project are as follows: 1) the development of an integrated mathematics and physics module (in English and Spanish) that is based on mathematical modeling, implementation research, and teaching and learning research that are aligned with state/national standards for science and mathematics, and the national standards for technology education, to include cross-curricular inquiry activities that aim to emphasize depth rather than breadth of content knowledge and reasoning skills, and 2) the improvement of pre-service science and math teaching and learning by refocusing methods course content to include inquiry based activities and constructivist based teaching to gain an appreciation of how science and math can be integrated in classroom instruction.

Component 1: Development of an Integrated Mathematics and Physics Module

The focus of the curriculum module will be the integration of physics and mathematics content through mathematical modeling. Inquiry activities constitute the heart of this curriculum for undergraduates who will teach students in grades 6, 7, and 8. Inquiry activities will focus on mathematical modeling, which will unify key physics ideas (force, motion, and momentum) with reciprocal big ideas in math (measurement and estimation, ratio and proportion, functions, and transformations). Based on a recent National Research Council Report, *Learning to Think Spatially* (2006), the curriculum component aims to utilize relevant technologies that serve as resources to support the process of developing spatial reasoning in science and mathematics. The technology plays a key role in the project by focusing on the use of interactive software (e.g. spreadsheets, motion sensors, PASCO Data Studio) to learn science and mathematics at a more conceptual level.

Modeling was selected as the unifying concept/theme for our project because it provided an opportunity to test the proportion/hypothesis/construct of "less is more." As a unifying theme, pre-service teachers would have opportunities to approach teaching science and math, less from a coverage perspective and more from a depth perspective. A scientific model is a testable idea that tells a story or helps provide an explanation about what happens in nature. Such a definition has been widely accepted. By using modeling, teachers will have opportunities to teach a set of ideas that explain a process or occurrence which can predict how certain scientific phenomena will occur or behave while under observation. Teachers, for example, can examine the powerful ideas related to Sir Isaac Newton's geometrical models of force and motion or the ideas that support pictorial and physical models of the solar system and apply them to their understanding of student learning and to curriculum development. In practice, scientific models may include or consist entirely of mathematized descriptions of phenomena. A scientific model becomes a mathematical model if the model represents a real-world situation with a mathematical construct involving mathematical concepts and tools. A mathematical model can embody foundational learning in such areas as algebra, geometry, and statistics along with their algorithms and formulae.

Another reason that modeling was selected was because of the significant problems facing modeling as an area of research in science and math education. Some of these problems identified by Niss (2001) include: 1) how students learn to critically and reflectively analyze and assess a given model: justification, behavior, mathematical properties, and possible alternatives to it; 2) what difficulties students have in acquiring and consolidating these critical learning and analytical skills; and 3) how do students learn these skills which depend on the specific, scientific contexts in which the model is constructed. Though difficult, responding to these three questions about student learning through modeling is not only a fundamental goal of the Project SMART, but also a goal of science and math education. Pollak (2003) cites other crucial problems related to using models and modeling in formal classroom settings which include how to connect science and math to the "rest of the world." He claims that, "What is usually missing is the understanding of the original situation, the process of deciding what to keep and what to throw away, and the verification that the results make sense in the real world" (p. 650).

Component Two: Improvement of Pre-service STEM Teacher Preparation

The *National Science Education Standards* (1996) authored by the National Research Council (NRC) and *The Principles and Standards for School Mathematics* (2000) authored by the National Council of Teachers of Mathematics (NCTM) emphasize a critical need for students to study both science and mathematics in real-world contexts. Both documents stress the importance of inquiry-based learning when students examine problems and situations related to physical phenomena. The ability to represent situations verbally, numerically, graphically, geometrically, or symbolically can be fostered (NRC citing NCTM, p. 219) through inquiry approaches that integrate science and mathematics in classrooms and provide rich learning experiences for students (National Research Council, 2000).

Building on constructivist theories of scientific and mathematical knowledge (von Glasersfeld, 2001), a solid theoretical foundation for modeling as an inquiry-based approach encompasses the idea that representations (mathematical and non-mathematical), discourse, argumentation, and negotiation and validation of models. Models are critical to the implementation of inquiry-based activities in classrooms. These ideas related to constructivist-driven inquiry have implications for both science and mathematics education in terms of understanding the individual and social construction of scientific and mathematical knowledge.

An important question asked by many teachers, mathematicians, and scientists is "What do we want students to learn and know in mathematics and science?" Identifying what insight, knowledge, and skills students need is a difficult task especially as teachers, scientists, and mathematicians may respond quite differently. Though difficult, identifying these elements of student learning is a fundamental goal of mathematics and science education. Although some critics of constructivism claim that many scientific concepts or skills are not in the realm of student experience, von Glasersfeld (2000) makes the distinction between conventional facts that students must possess permanently and concepts that are best constructed by a thinking, rational being. He writes, "Whatever is conventional must be learned, so to speak, verbatim; what is based on rational operations, should be understood" (p. 2). One of the most intriguing aspects of constructivism is that it allows one to look more closely at the nature and importance of certain skills within given contexts and why those skills may or may not be important. For example, solving a proportion can be described as an important mathematical skill, but why this skill is important is a fundamental question teachers try to answer on a fairly routine basis. Key personnel in Project SMART will demonstrate such constructivist teaching practices when the curriculum modules are presented during the university methods courses.

Our approach used in the curriculum includes a number of hands-on, inquiry-based activities that lend themselves to constructivist-based implementation (inquiry) and are representative of ideas that are currently introduced in both science and mathematics classes, but in isolation. Most pre-service teachers rarely see how these ideas form a bridge between science and math. Furthermore, our approach provides an example of the kind of research recommended by the International Commission on Mathematics Instruction (ICMI) (2003) on teacher education.

Project Design

Participants. Each year, a total of 20 (60 over three years) pre-service 4-8 middle school science and math teachers will participate. These teachers are traditionally enrolled in and required to complete two courses in the final academic year prior to graduation. These courses are entitled, MSED 4310, Teaching *Mathematics in the Intermediate and Middle Years*, and MSED 4311, *Teaching Science in the Intermediate and Middle Years.* These courses explore the methods of teaching mathematics and science, emphasizing the equity principle (mathematics and science for all) and development of conceptual understanding of critical mathematics and science topics. They also explore what it means to "know" and "do" mathematics and science by relying on constructivist principles for learning and teaching.

Measurement and Estimation

Some mathematics methods courses present activities that may or may not promote learning of estimation as anything other than a de-contextualized skill. Such activities are not necessarily based on an understanding of pre-conceived beliefs or pre-conceptions about estimation. We argue that learners' methods of estimation rely heavily on a pre-conceived belief that estimation is but a simple means or procedure to a far more important end – finding the "exact" or "true" answer. The belief that mathematics is an "exact" discipline (that mathematics does not allow for "error") prohibits students from understanding and appreciating the importance of estimation as a proficiency, one we argue relies on important mathematical constructs such as measurement, ratio, and percent. The latter argument has an impact on the training of future math teachers. We argue that students typically rely on methods and or procedures of estimation of discrete quantities for all situations regardless of context. This is typically due to overemphasis on very routine calculation problems (Kilpatrick, et al., 2001).

Student estimation of continuous quantities (such as length or angle) usually relies on simple rounding techniques (as in whole number computation) and dismissal of "error" leading to limited understanding about precision and accuracy. Such reliance makes it difficult to determine or teach a uniform definition of estimation, which includes determining the appropriateness of the estimation (different for discrete and continuous quantities). Furthermore, it exposes the need for students to develop the connection between continuity and number (Goussinsky, 1959). The challenge for mathematics educators and for those involved in the professional development of teachers is how to develop estimation proficiency and skill in learners rather than teaching estimation as a separate mathematics topic or subject, devoid of context beyond its use in simple whole-number calculations.

Estimation is a mathematical strand requiring more emphasis at both elementary and middle school levels. However, we argue that estimation is a complex topic, necessitating the need to emphasize it as a means to determine an informed solution to a given problem. We agree with Kilpatrick et al. (2001, p. 216) who state, "Estimation requires a flexibility of calculation that emphasizes adaptive reasoning and strategic competence, guided by children's conceptual understanding of both the problem situation and the mathematics underlying the calculation." Students could use varied approaches to finding a solution to a complex problem. Some have argued that what is involved in finding that solution, such as the use of multiple representations, has a great impact on how students understand and use estimation (Ainsworth, Bibby, & Wood, 2002). Prior research has typically tried to address estimation (or has involved estimation) in the separate contexts of learning or using estimation with discrete quantities (Hogan & Brezinski, 2003; Montague & van Garderen, 2003) as well as continuous quantities (Clements & Burns, 2000; Keiser, 2004; Van den Heuvel-Panhuizen, 2003).

Unlike estimation, measurement as a mathematical concept has been duly emphasized and touted in both state and national standards. Mathematics methods courses for pre-service teachers typically focus on learning and teaching both formal and informal measurement (with and without standard units). Research studies in science education that focus on children's experiment design reveal how and why students use measurement during the process of inquiry (Petrosino, Lehrer, & Schauble, 2003). The activities involving measurement and estimation coupled with those involving discrete estimation should enhance learning estimation as proficiency rather than a de-contextualized skill. Such research has a significant impact on teacher preparation in both content and pedagogy.

We further argue that estimation promotes mathematical modeling skills. It helps students connect mathematical structures and methods to real-life (real-world) situations – related to measurement error, experimental error, and accuracy. In the realm of mathematical modeling, it is important to understand how students treat error when trying to solve a problem especially within the context of inquiry. Such understanding clarifies the role that estimation must play in determining a well-informed decision about a result and, furthermore, how students connect a more abstract view of mathematical structures and symbols to real-world situations. Table 1 provides the topics, research-based activities, and objectives that will be introduced into undergraduate math and science methods courses.

Topic	Activity/Activities	Objective(s)
Length	*Guess and Measure*	Estimating before using standard units
	Change of units	Understanding informal units; Making rulers
	More than One Way to Measure	Different ways to measure the same length with one ruler
Area	*Irregular Figures*	Estimation by decomposition into familiar shapes
Angles	*Creating a Protractor (Creating Unit Angles)*	Understanding unit angles and their attributes
Volume	*Comparing Tubes*	Understanding 3-D measure
	Fill and Compare	Understanding 3-D measure

Table 1 Measurement and estimation activities and objectives

Mathematical Modeling and Kinematics

Most undergraduate physics instruction provides curriculum material in kinematics that involve some lab experiments with activities such as rolling a ball on a track, using a fan cart attached to a ticker-tape timer, and observing a fan belt attached to two pulleys. However, these experiments do not involve collection and analysis of real-time data as an integral part of the construction of the mathematical models for motion. Quantitative descriptions of position and time are only briefly discussed while more emphasis is placed on qualitative graphing (position-time and velocity-time graphs). Furthermore, the experiments can more aptly be described as demonstrations that are followed immediately by introduction of formal (symbolic) mathematics, including precise definitions (e.g., instantaneous velocity) and procedures (e.g., finding the area under a graph). In these modules, the learner is given more guidance through the experiments, which require direct instruction from the facilitator or teacher. There is less emphasis on an inquiry process that might allow a learner to formulate his or her own mathematical models of the physical phenomena. The module on kinematics leaves several areas open for strengthening its inquiry-based approach to studying uniform and non-uniform motion.

The researchers are developing a kinematics unit based on 1) activities that the Co-PI is using to engage middle school students and in-service teachers in learning physics content (Robertson, 2007), and 2) activities constructed and research conducted by the PI on mathematical modeling of motion (Carrejo, 2004; Carrejo & Marshall, 2007, Marshall & Carrejo, 2008). This curriculum facilitates a classroom environment for studying mathematical modeling from a constructivist point of view. Building on the assumption that the teachers' prior knowledge might be extremely limited or include only a procedural understanding of motion and associated mathematical models, the primary goal of the implementation is to facilitate a more conceptual understanding of both uniform and non-uniform motion equations. Table 2 provides the topics, research-based activities, and objectives that will be introduced into undergraduate math and science methods courses.

Topic	Activity/Activities	Objective(s)
General motion	*Invent and describe a motion*	Identify critical concepts in describing motion (position and time).
		Differentiate position and distance, clock time and time of travel.
		Understand that position can be predicted from a starting position and time and knowledge of how position is changing with time (velocity).

Constant velocity	*Graph the relationship between the position of a rolling ball and elapsed time*	Explain a procedure for finding the position of the object at some future time, t, using only a data table.
		Use a graph to predict the position of an object at some future time.
		Interpret the slope of a position-time graph as the velocity of a moving object.
		Be able to draw a best fit line to represent a set of data. Be able to explain why a best fit line is a better representation of nature than the actual data points.
		Derive an algebraic equation to represent an object moving with constant velocity.
Accelerated motion	*Acceleration with a spark timer*	Create a position-time and velocity-time table for accelerated motion
		Find an average velocity for an accelerating object during successive small intervals
		Predict the future position and velocity of an accelerating object
		Create an equation for uniformly accelerated motion

Table 2 Kinematics activities and objectives

Research

Researchers and graduate students will conduct qualitative analyses of videotaped teacher and student learning episodes based on grounded theory (Cobb, Stephan, McClain, & Gravemeijer, 2001; Glaser & Strauss, 1967; Mann, 1993). The goal of such analyses is to identify learning episodes and characteristics of scientific and mathematical reasoning. Data collection will involve whole class and group observations during the pre-service educators' methods courses, as well as in middle school classrooms. Qualitative notes, including researcher reflections, will be compiled from this analysis. Classroom artifacts, including representations from individual groups, as well as representations created from whole class discussions will be analyzed.

The first phase of analysis involves examining the video and transcripts chronologically to identify episodes. An episode is characterized as a segment in which a mathematical theme(s) is the focus of activity and/or discourse. Observations and conjectures are developed about reasoning and the context in which the reasoning takes place. As described by Cobb et. al (2001), "The result of this first phase of the analysis is a chain of conjectures, refutations, and revisions that is grounded in the details of the specific episodes" (p. 128). In grounded theory, three types of coding are typically involved in data analysis:

- Open coding (creating categories for data),
- Axial coding (using open codes and researchers' catalogue of data to determine characteristics or dimensions of categories and create a core category or categories),
- Selective coding (data collection and analysis focuses on the core category and supporting categories).

Through open and axial coding, patterns in thinking as well as emerging mathematical constructs will be identified throughout the implementation of the modules. Key episodes for the study will be utilized to indicate the scope and breadth of qualitative analysis. They need not be interpreted as isolated incidents to support certain claims; rather, they highlight the emergent patterns and constructs that are reflected throughout the data and reflect the thinking throughout the modelling process. Selective coding of the results will benefit the researchers for further study; given the creation of core categories from this study, we will attempt to identify these categories with other learners in different environments who are involved in the same implementation of the modules. Researchers will study two learning environments -- university methods courses and classroom instruction.

The approach used to code data fits well with constructivist views on learning, whereby learners rely on prior knowledge or what pre-conceptions they may bring with them regarding certain phenomena. Learners in general, as with the participants in this study, have time and space to make sense of their experiences. In this sense, the "core" of a grounded theory will remain the same across classroom settings (university methods courses and middle school classrooms) while approaches to data collection and interpretation will reasonably change to not only reflect the setting but also be useful enough to apply to other classroom settings. Table 3 presents the major objectives that contribute to the institutionalization of the curricular component of our project, along with the research methodology, which will be used to collect and analyze the data.

Goal 1: *Develop/design* a rich physics and mathematics content module through mathematical modeling	
Objectives	*Research Methodology*
To write a cross- curricular science and math set of modules in English and Spanish using a collaborative team approach involving key personnel from the Colleges of Education, and teachers/administrators.	• Qualitative research analyses of data collected will take place during the methods courses involving pre-service teachers which will target/identify learning episodes and characteristics of scientific and mathematical reasoning through the implementation of the cross curricular science and math modules. • Results from both qualitative and quantitative data analysis will provide support for evaluating the effectiveness and quality of the curriculum modules and determining if the goals of the curriculum were being met.
Goal 2: Plan and demonstrate innovative constructivist practices (strategies) to *use/implement* during pre-service middle school science and math methods coursework	
Objectives	*Research Methodology*
To implement the STEM content in the cross curricular modules during the methods courses for pre-service teachers in a way that demonstrates the pedagogical skills for inquiry teaching and learning.	• Data will be collected and analyzed from pre-/post science, math, and technology knowledge instruments and attitude inventories to calculate an effect size. • Data will be gathered and analyzed from the efficacy surveys. • Qualitative video analysis of pre-service teachers as they learn about and complete tasks in the modules to examine the interactions • Scores from previous the content and pedagogy mandated licensure exams (TExES) will be collected, analyzed, and compared with those from pre-service teachers participating in our project. There will be a set of matched control groups of pre-service teachers who did not participate whose scores will be compared on content knowledge and pedagogical competencies to measure the strengths of the relationship for each test.

Table 3 Research goals, objectives, and evaluation methods

References

Ainsworth, S., Bibby, P., & Wood, D. (2002). Examining the effects of different multiple representational systems in learning primary mathematics. *Journal of the Learning Sciences, 11*(1), 25-61.

Bailer-Jones, D.M. (2002). Scientists' thoughts on scientific models. *Perspectives on Science 2002*, *10*(3), 275-301.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of the Learning Sciences, 2*, 141-178.

Carrejo, D., & Marshall, J. (2007). What is mathematical modeling? Exploring prospective teachers' use of experiments to connect mathematics to the study of motion. *Mathematics Education Research Journal 19*(1), 45-76.

Clements, D.H., & Burns, B.A. (2000). Students' development of strategies for turn and angle measure. *Educational Studies in Mathematics, 41*, 31-45.

Cobb, P., Stephan, M., McClain, K., & Gravemeijer, K. (2001). Participating in classroom mathematical practices. *Journal of the Learning Sciences, 10*(1&2), 113-163.

Glaser, B.G., & Strauss, A.L. (1967). *The discovery of Grounded Theory: Strategies for qualitative research*. New York, NY: Aldine de Gruyter.

Glasersfeld, E. v. (2000). *Radical constructivism and teaching*. Available: http://www.umass.edu/srri/vonGlasersfeld/onlinePapers/html/geneva/
Glasersfeld, E. v. (2001). The radical constructivist view of science. *Foundations of Science*, *6*, 31-43.
Goussinsky, B. (1959). *Continuity and number*. Israel: Government Printing Press.
Hispanic Outlook in Higher Education. (May, 2006). *The top 100.* Available: http://www.hispanicoutlook.com/top100.htm
Hogan, T.P., & Brezinski, K.L. (2003). Quantitative estimation: One, two, or three abilities? *Mathematical Thinking and Learning, 5*(4), 259-280.
International Commission on Mathematics Instruction. (2003). *ICMI Study 14: Applications and modeling in mathematics education [Discussion document]*. Kassel, Germany: University of Kassel.
Keiser, J.M. (2004). Struggles with developing the concept of angle: Comparing sixth-grade students' discourse to the history of the angle concept. *Mathematical Thinking and Learning, 6*(3)*,* 285-306.
Kilpatrick, J., Swafford, J., & Findell, B. (2001). *Adding it up: Helping children learn mathematics*. Washington, DC: National Academy Press.
Lee, O. (2002). Science inquiry for elementary students from diverse backgrounds. In W. G. Secada (Ed.), *Review of Research in Education, 26*, 23-69. Washington, DC: American Educational Research Association.
Lee, O. (2003). Equity for culturally and linguistically diverse students in science education: A research agenda. *Teachers College Record, 105*, 3, 465-489.
Lee, O. (2005). Science education and English language learners: Synthesis and research agenda. *Review of Educational Research, 75*(4), 491-530.
Mann, M. P. (1993). Grounded Theory and classroom research. *Excellence in College Teaching, 4*, 131-143.
Montague, M., & van Garderen, D. (2003). A cross-sectional study of mathematics achievement, estimation skills, and academic self-perception in students of varying ability. *Journal of Learning Disabilities, 36*(5)*,* 437-448.
Marshall, J., & Carrejo, D. (2008). Students' mathematical modeling of motion. *Journal of Research in Science Teaching 45(2)*, 153-173.
National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics.* Reston, VA: Author.
National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.
National Research Council. (2000). *Strengthening the linkages between the sciences and the mathematical sciences.* Washington, D.C.: National Academy of Sciences.
National Research Council (2006). *Learning to Think Spatially*. Washington, D.C.: National Academy of Sciences.
National Science Board (2006). *America's pressing challenge – Building a stronger foundation: A companion to Science and Engineering Indicators 2006.* Arlington, VA: National Science Foundation.
Niss, M. (2001). Issues and problems of research on the teaching and learning of applications and modeling. In J.F. Matos, W. Blum, S.K. Houston & P. Carreira (Eds.), *Modeling and mathematics education: ICTMA 9 – Applications in science and technology* (pp. 72-88). Chichester, England: Horwood Publishing.
Petrosino, A., Lehrer, R. & Schauble, L. (2003). Structuring error and experimental variation as distribution in the fourth grade. *Mathematical Thinking and Learning, 5*(2&3), 131-156.
Pollak, H. O. (2003). A history of the teaching of modeling. In G. M. A. Stanic & J. Kilpatrick (Eds.), *A history of school mathematics* (Vol. 1, pp. 647-672). Reston, VA: National Council of Teachers of Mathematics.
Robertson, W.H. (2008a). *Developing problem-based curriculum: Unlocking student success utilizing critical thinking and inquiry*, Kendall Hunt Publishers*,* Des Moines, Iowa, 2008.
Robertson, W.H. (2008b). *Dr. Skateboard's Action Science*, Disc 2 Day Publishers*,* Tempe, Arizona.
Rosebery, A. S., Warren, B., & Conant, F. R. (1992). Appropriating scientific discourse: Findings from language minority classrooms. *Journal of the Learning Sciences, 21*, 61-94.
Sowder, J. (1992). Estimation and number sense. In D.A. Grouws (Ed.), *Handbook of research on teaching and learning mathematics* (pp. 371-389). New York, NY: Macmillan.
Van den Huevel-Panhuizen, M. (2003). The didactical use of models in realistic mathematics education: An example from a longitudinal trajectory on percentage. *Educational Studies in Mathematics, 54,* 9-35.