AC 2012-5559: LEARNING COMMON CORE MATH CONCEPTS WITH WISENGINEERING

Crystal Jean DeJaegher, University of Virginia

Crystal J. DeJaegher is a first-year doctoral student in the Department of Instructional Science and Technology within the University of Virginia's Curry School of Education studying under Dr. Jennie Chiu. She holds a M.S. in secondary education from Indiana University. Experiences as a high school teacher have informed her research interests with a focus on STEM education and using technology to improve learner outcomes.

Prof. Jennifer L. Chiu, University of Virginia
Dr. M. David Burghardt, Hofstra University
Dr. Deborah Hecht, City University of New York

Center for Advanced Study in Education, CUNY Graduate Center

Peter Thomas Malcolm, University of Virginia, Charlottesville

Peter T. Malcolm, p.malcolm@virginia.edu, is a Graduate Research Assistant in the Curry School of Education at the University of Virginia (UVA), Charlottesville. His primary interest is in developing software to help elementary and middle school students collaborate to understand and interact with STEM concepts.

Mr. Edward Pan, University of Virginia

Learning Common Core Math Concepts with *WISEngineering*

Abstract

WISEngineering is an innovative, free online learning environment that supports students through engineering design projects designed to improve science, technology, engineering, and math (STEM) learning in middle and high school classes. *WISEngineering* builds from an informed engineering design pedagogy, knowledge integration learning framework and the open-source Web-based Inquiry Science Environment technologies. *WISEngineering* uses engineering design modules to facilitate engineering habits of mind such as systems thinking, creativity, optimism, collaboration as well as standard-based mathematics and science concepts. In these modules, students use CAD technologies and digital fabrication to create, build, and refine their designs. The environment leverages technologies such as an electronic design journal, portfolio and "design wall" that enables students to create, share, critique, and communicate with their peers. These engineering design projects give students a context and real-life application for learning math and science concepts.

The Community Challenge project sequence engages 7th grade students in the design of their local community. The first two-week project guides students through the design of a community building, the second project involves students in designing a community garden, and the third project engages students in designing windmill and solar panel systems to help power their building and garden. This presentation focuses on the first project in the sequence, the Community Building project. Students are given volume and surface area constraints and specifications for their building design. Based on these parameters, students must learn and apply several Common Core Mathematical Standards of Geometry, Ratios and Proportional Relationships, and Expressions and Equations. Once students have their initial design, they create and refine models using digital fabrication technologies. The Community Building project leverages the success of the Skyline Design project that has demonstrated success improving students' understanding of standards-based math concepts.

This paper provides an outline of a work-in-progress study of the Community Building project. This implementation involves around 200 7th grade low performing students in an urban middle school. Pretest, posttest, and embedded assessments, as well as targeted interviews, have been designed to assess learner outcomes in mathematical understanding, engineering habits of mind, and an interest in STEM subjects.

Introduction

Engineering design requires students to apply science, mathematics, and engineering concepts to solve open-ended problems under given specifications and constraints. Design thinking reflects students' ability to scope problems, explore options, develop solutions, test, and iteratively optimize products using their STEM skills[1]. Unfortunately, engineering design can be difficult to learn and teach at K-12 levels due to lack of engineering experiences and training[2]. The open-ended nature of design and constraint-based reasoning poses difficulties to students and teachers[3]. Students have trouble monitoring their learning with any degree of accuracy, using trial-and-error approaches instead of careful analysis of their tasks. Students may end up with a good product when using a trial and error method, but hardly any learning may take place in the process.

Effective interventions for mitigating these problems are difficult to develop without an in-depth understanding of K-12 students' understanding of design and design thinking. The *Engineering in K-12 Education* report recommended that new developers and implementations of engineering curricula should include research that analyzes what works in classrooms and why[1].

WISEngineering is an online environment developed to answer this call (www.wisengineering.org). It provides a learning management system to guide students through engineering design projects. *WISEngineering* also provides teacher and researcher tools to monitor and assess student understanding. Assessments technologies give teachers a viable way to evaluate different approaches and solutions derived by students through each design challenge. The *WISEngineering* system builds upon over 20 years of technology-enhanced learning research in science as well as prior constructionist, project-based and design-based efforts.[4]

Critical to *WISEngineering* is the ability for students to learn relevant STEM concepts and skills in a just-in-time manner. *WISEngineering* employs an *informed engineering design pedagogy* developed and validated through the conduct of several projects.[5] In this approach, students engage in a series of *knowledge and skill builders* (KSBs), which are short, focused activities related to the content knowledge needed for design solutions. Using KSBs enables students to reach solutions informed by knowledge and skill, as opposed to learning from trial-and-error design where conceptual closure is often not attained. *WISEngineering* provides support for students engaging in design projects that provide real-world applications and relevance to STEM courses. Each project in *WISEngineering* targets specific standards-based math or science concepts as well as relevant engineering habits of mind. *WISEngineering* operates under assumptions that the engineering design pedagogy will engage students in learning math; that web-based learning enables students to learn in smaller groups with more individualized and motivating instruction; that contextualizing math within design challenges will lead to increased understanding of mathematical concepts and engineering design processes and thinking.

To explore the potential of *WISEngineering* to teach mathematics concepts through informed engineering design approaches, this paper examines a work-in-progress pilot implementation of the Community Building project with 7th grade students. Specifically, this study is designed to answer the following questions: 1) How can a technology-enhanced engineering design module help students understand 7th grade common-core mathematics concepts? 2) How can an informed engineering design approach help students develop an understanding of engineering design and habits of mind?

Background

Engineering habits of mind include systems thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations.[1] Related design skills include divergent–convergent thinking, making decisions, handling uncertainty, generating solutions as a team, and communicating with multiple representations.[6] Mathematical habits of mind encompass similar processes: problem solving, reasoning and proof, making connections, communication, and representation.

WISEngineering provides support for students as they solve authentic and relevant problems and in the process help them make decisions in light of uncertainty, generate solutions to problems that have no one distinct answer, and develop criteria for their designs and understanding. Students are encouraged to use multiple forms of representation and develop communication skills to collaborate with other students and design teams. In addition, many projects leverage CAD programs such as ModelMaker and easy-to-use digital fabricators like Silhouette printers to engage students in authentic CAD/M experiences.

Building from learning sciences research

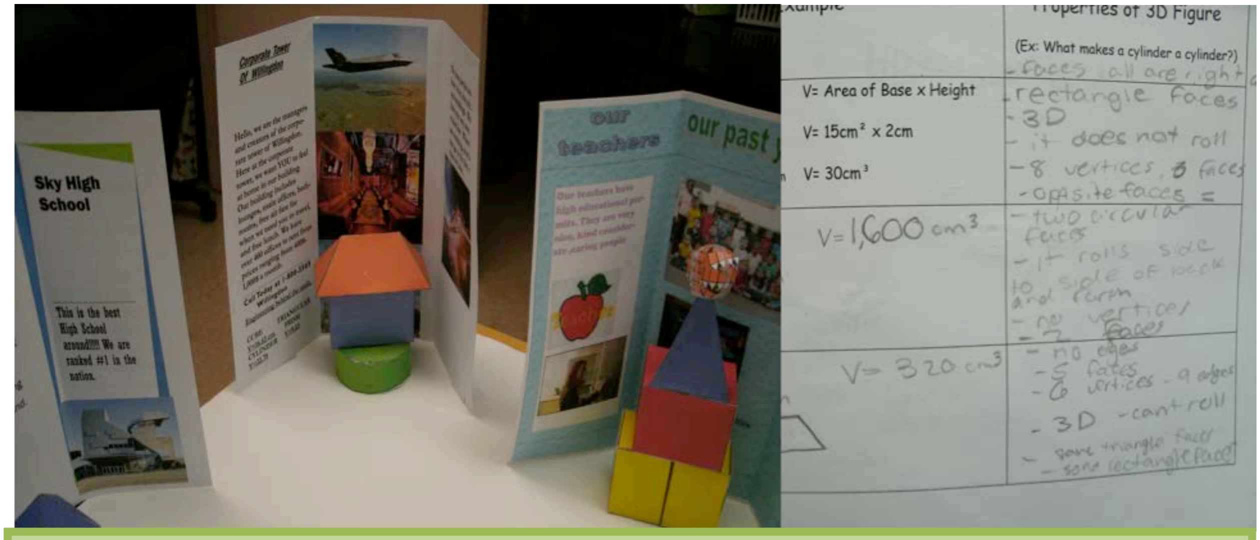
WISEngineering uses the *knowledge integration* (KI) learning framework to guide curriculum development and research. KI builds on decades of empirical studies on student and teacher learning in science and engineering classrooms.[7] KI is a tested, research-based perspective that brings together recent trends in developmental, constructivist, sociocultural, and cognitive perspectives on learning. According to KI, learners build understanding by adding, sorting, evaluating, distinguishing, and refining ideas from classes, everyday experiences, and cultural expectations. KI is based on a large body of literature demonstrating that learners come to class with rich, intuitive ideas about phenomena developed from their varied experiences, intellectual efforts, and interpretations of the natural world.[8] These diverse ideas serve as a rich basis for engineering design projects.

The KI instructional pattern identifies learning processes that are essential for helping students make connections between ideas and develop coherent understanding: eliciting, adding, distinguishing, and sorting ideas. The KI framework aligns well with engineering design projects.[9] *WISEngineering* uses KI as a learning framework to guide curriculum design, assessment, and refinement, enabling us to document the ideas that students hold about various concepts in different domains as well as how these ideas are connected.[10] For example, many students struggle to make connections from topics in math to their everyday life. Engineering design projects provide students with experiences where they see the relevance of math outside of math class. KI provides a framework to look at student understanding of math concepts and connections among ideas.[11]

Informed engineering design pedagogy

WISEngineering draws heavily from *Informed Engineering Design*.[5] Informed design is a pedagogical approach that engages students in the development of knowledge and skills relevant to the design challenge at hand. Instead of trial-and-error problem solving, students apply their understanding to create *informed* design solutions. Thus, students are motivated to learn in a just-in-time manner through explicit learning events called knowledge and skill builders (KSBs).KSB's provide structured inquiry learning about key STEM concepts that underpin the design challenge.

The *WISEngineering* team has been engaged in preliminary work to study the feasibility of using informed engineering design to improve mathematics learning. A team of teachers, administrators, engineers, and educational researchers, have implemented an instructional unit termed the *Skyline Design Challenge* (Figure 1). The unit focused on the sixth- and seventh-grade mathematics curriculum using informed engineering design and digital fabrication. The unit was a paper- and-pencil prototype for the web-based *WISEngineering* project. The development process included math teachers to ensure the content and activities were aligned with the proposed learning goals, the activities were realistic for the target student group (sixth graders), and the math and engineering were integrated at a high quality. Pre-post content assessments were developed to assess student learning, using questions from validated standardized state assessments as well as affective and engagement measures.



Skyline Design Challenge: An island named Willingdon has just been human made. The president of the island is searching for young, creative, and intelligent engineers who can build a city in Willingdon. Your challenge is to design an original model of a skyscraper building that will be placed in the new city. The president will need to see your plans, measurements, and a model in order to consider using your design. The skyscraper must stand up on its own and should include at least three different three-dimensional shapes. The president has requested that the skyscraper also have a volume between 150cm³ and 250cm³ and that the surface area of the model skyscraper be between 170cm² and 350 cm². In addition, you may only use a glue stick to assemble the model skyscraper. You will have four class periods to complete the challenge.

Figure 1. Description of the Skyline Design Challenge, with example student final projects and student work.

Skyline was piloted with 50 sixth-grade students during 12 mathematics classes. The students were highly engaged in implementing the unit, creating virtual designs with ModelMaker™; and printing and cutting their designs using a Silhouette™ fabricator, with the teacher's assistance. Students used the software to check their calculations of area and volume.

Student learning results demonstrated an increase from the pre to post assessments on every math content question. This increase ranged from 7% to 50% on the individual questions, with an average increase of 23% across all items, with significant overall improvement at the $p < 0.05$ level. Additionally, students' perceptions of themselves improved greatly. After the implementation, over 14% more students rated themselves as "excellent" math students on the post attitude assessment.

***WISEngineering* technologies development**

WISEngineering builds upon these pilot studies and leverages affordances of a web-based environment to provide rich learning experiences for students. A multidisciplinary team of engineers, educational researchers and evaluators, practicing teachers, and software engineers across universities develop *WISEngineering* technologies and curricula. Project development includes multiple cycles of usability testing and formative evaluation of all project technologies and materials.

WISEngineering builds upon the open-source capability of the Web-based Inquiry Science Environment (WISE4; http://wise4.berkeley.edu). WISE4 has been developed and refined to provide pedagogical features for teachers, researchers, and students to support implementation of upper elementary to college level inquiry-based science projects.[12] Free to the public, WISE4 enables anyone to develop curriculum and author content such as online brainstorms and discussions, explanation scaffolding, model building, drawing, and online journals. WISE4 offers a library of tested curricula to implement in classrooms, and enables teachers, researchers, and developers to customize the curricular modules. *WISEngineering* leverages WISE4 functionality to provide a free, online environment that scaffolds engineering design projects for students. Students collaborate as they ideate, develop and test solutions, refine and retest their designs, and critique and share their projects, all within the system. *WISEngineering* allows teachers to interact, give feedback, and monitor student work using teacher tools. Teachers can grade student work for a particular step or for a specific student group. They can look on a class dashboard to see individual groups' progress through the project. If teachers see particularly interesting work from certain students, they can check a box to anonymously flag the work and put it up on a class screen. *WISEngineering* also provides functionality to researchers such as logging student interactions with the environment at different levels. Embedded assessments enable researchers to capture student thinking during the process of inquiry and design. Many project-based approaches struggle to assess individual learning in the context of the group. The *WISEngineering* environment can captures and assess individual and small group learning within and across design projects.

Through close collaboration with the project team and iterative refinement with user testing, the following engineering design technologies are featured within the *WISEngineering* environment:

Engineering design navigation system. Many students have little understanding of what engineering entails. Making a design process explicit helps students understand and perform engineering design. *WISEngineering* includes explicit guidance for processes of engineering design that help students develop an understanding of engineering design. This "engineering design map" scaffolds students to identify specifications and constraints, develop a knowledge base, ideate solutions, build prototypes, implement and test solution, evaluate and refine designs, and critique and give feedback on others' designs (Figure 2).

*Design journal***.** The design journal enables students to add ideas, sketches, pictures, and designs within the system. The journal is accessible at any point throughout the project and records all student work throughout the project. The design journal contains students' initial, revised, and final designs for their projects.

Design portfolio. The design portfolio enables students to select pieces of their design journal to share or communicate their project with others. This is typically used at the end of the project to present to their peers or to turn into the teacher for assessment.

Design wall. These steps allow students to collaborate around projects by posting on a "wall," and comment or critique others' design solutions. Students can use the design wall to share with team members who may be within their same class or even across schools running the same project. The design wall leverages social media functionality to encourage students to share, learn from, and extend each other's expertise.

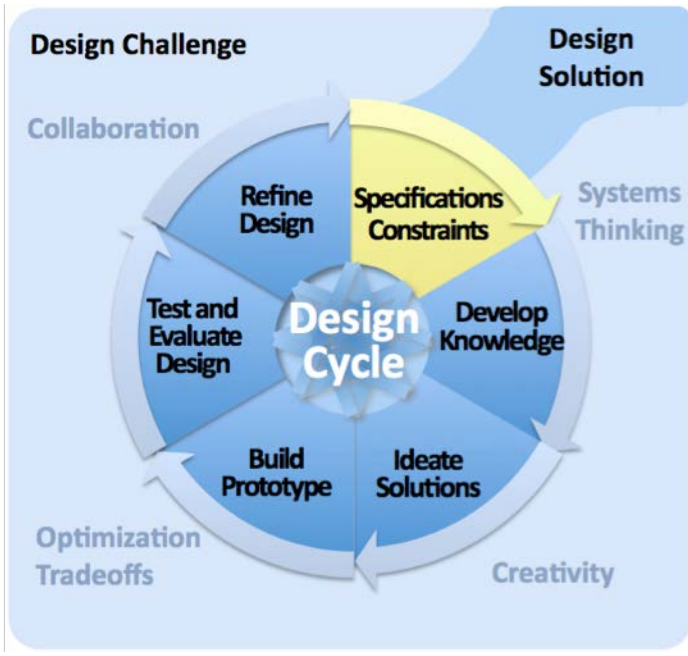


Figure 2. Explicit Design Cycle used in WISEngineering projects.

Community Building project development

This paper introduces the work-in-progress pilot implementation of the first *WISEngineering* module, the Community Building Design Challenge. The Community Building module represents the first of a sequence of three two-week design projects for use in seventh-grade mathematics classes.

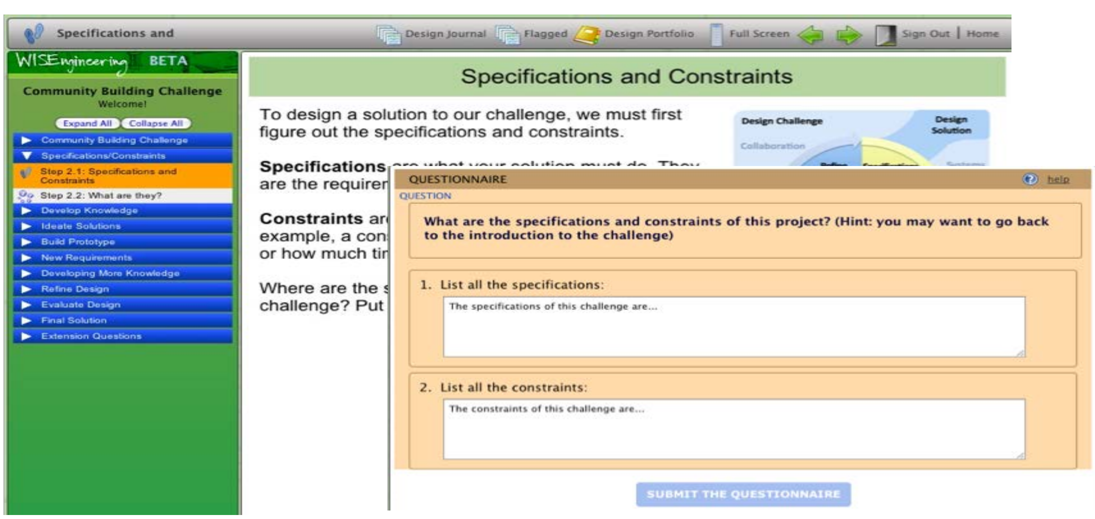


Figure 3. Screenshot of *WISEngineering* Community Building Challenge. Links to the Design Journal and Portfolio persist at the top of the student screen.

Each unit covers Common Core standards for learning in mathematics including geometry, proportional relationships, and expressions and equations through the lens of engineering design. The Community Building project draws heavily from the Skyline Design Challenge and combines the success of the paper-and-pencil version with new *WISEngineering* online design technologies.

In the Community Building project, students are charged with creating a community center dedicated to serve the people in their town. They design an original model of a community center that must include at least three different three-dimensional shapes, with specific volume, surface area, and cost constraints (Table 1). Targeted math learning goals include recognition of three-dimensional shapes, calculating volume and surface area for two-dimensional and three-dimensional shapes, as well as calculations involving decimals and percents (objectives 7.G.1-7.G.6 in the Common Core Standards).

Table 1. Activity Description of Community Building Challenge.

Engineering Activity Steps	Community Building Challenge Activities
Design Challenge	Introduces design challenge, engineering design processes and map, design journal
Specifications and Constraints	Students learn about specifications and constraints for the project, and answer open-response embedded assessments to reinforce understanding.
Develop Knowledge	Students use online tutorials to develop understanding about 3D objects, how to calculate surface area and volume. Provides off-line practice calculations by hand in linked PDF files.
Ideate Solutions	Use internet and other resources to find existing images and examples of community buildings, use drawing tools to sketch designs and use design wall to share with peers.
Build Prototype	Use ModelMaker and Silhouettes to design, build, and fabricate a prototype.
Evaluate Prototype	Use design wall to post CAD designs and get feedback from peers. Use hand calculations as well as CAD software to double-check surface area and volume calculations. Calculate costs of design.
Refine Design	Use evaluation and student feedback to iterate and refine their community building design solution.
Finalize solution	Decide on final solution to challenge. Create design portfolio from design journal to share work with peers and teacher.

Methods

Design-based educational research

Design-based learning research investigates learning in context by situated experiments within classrooms to test theories of learning in educational settings. These design-based experiments result in systematic design and refinement of generalizable principles for effective classroom instructional interventions.[13] In order to understand learning in authentic contexts, the system of the teacher, students, assessments, curriculum, and classroom culture, etc. must be used and carefully studied to reveal insights into cognition in classroom settings.[14] *WISEngineering* research uses design-based experiments in authentic classrooms to investigate, employ and refine principles concerning engineering education instruction in K-12 settings. This study in particular explores how engineering design pedagogy can help students learn standards-based mathematical content.

Participants

Around 200 students in an urban middle school will participate in the study. The school district is in state takeover and has been designated by the state as high need due to high evidence of student failure and large percentages of disadvantaged students. In 2008-2009 only 45% of the 8th graders scored at least proficient in math, failing to meet state standards for Adequate Yearly Progress. The student population includes disadvantaged and disengaged students that could greatly benefit from a new approach.

Teachers & implementation

Two teachers will implement all modules. The teachers were selected by administrators in the district that would be enthusiastic to work with our project as part of the development team. As part of the *WISEngineering* professional development, they have received training on relevant CAD/M software and hardware, and shown the *WISEngineering* website. A researcher will be present in the classroom for the first week to help with any technical issues.

Data sources

Teachers will administer a paper pretest and posttest to individual students before the units begin, and give the posttest following the conclusion of the project. The pretests and posttests assess the students' knowledge of the learning goals of the unit, including mathematical understanding, engineering habits of mind, and interest in STEM subjects.

Student textual responses to embedded assessments about their designs or mathematical calculations will be analyzed with a KI rubric[10] to illustrate the types of connections students make among their ideas. These embedded assessments will provide insight into how various phases of engineering design contribute to mathematical and engineering understanding.

Projected outcomes

We anticipate that students will make standards-based learning gains in mathematics. In addition, we believe the students will gain a better understanding of engineering design and engineering habits of mind through involvement with the WISEngineering Community Building Design Challenge. We also hope to see increased student interest in STEM, along with a greater number of students who show an interest in related careers.

We expect results from the Community Building project will demonstrate that using an informed engineering design pedagogy approach can help underperforming math students. Taking a just-in-time approach to learning and applying mathematical concepts gives students a relevant context for mathematics. Instead of thinking that math is only for math class, we hope that these engineering projects enable students to see the value of math outside of the classroom.

Additionally, we expect for 7th grade students to be able to easily navigate the *WISEngineering* environment and provide valuable feedback for further refinement of the system and curriculum in authentic classroom settings. Early studies using *WISEngineering* modules with college students have provided invaluable feedback to improve the technologies.

Bibliography

1. Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103-120.

2. Katehi, L., Pearson, G., Feder, M. A., Committee on K-12 engineering education., National Academy of Engineering & National Research Council (U.S.). (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington, D.C: National Academies Press

3. Bergin, D., Lynch, J., Khanna, S. K., & Nair, S. S. (2007). Infusing design into the G7-12 curriculum: two example cases. *International Journal of Engineering Education, 23*(1), 43-49.

4. Linn, M. C., Davis, E. A. & Bell, P. (2004). *Internet environments for science education.* Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

5. Burghardt, M. D., & Hacker, M. (2004). Informed Design: A contemporary approach to design pedagogy as the core process in technology. *Technology Teacher, 64,*(1). 6.

6. Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103-120.

7. Linn, M. C., & Eylon, B. –S. (2006). Science education. In P. A. Alexander & P. H. Winne (Eds.) *Handbook of Educational Psychology*, *2nd edition.* Mahwah, NJ: Erlbaum.

8. diSessa, A. (1988). Knowledge in pieces. In G. Forman & P. Pufall (Eds.), *Constructivism in the computer age* (pp.49-70). Hillsdale, NJ: Lawrence Erlbaum Associates.

9. Chiu, J. L. & Linn, M. C. (2011). Knowledge integration and WISE engineering. *Journal of Pre-college Engineering Education Research*, 1(1), 1-14.

10. Linn, M. C., Lee, H. S., Tinker, R., Husic, F., & Chiu, J. L. (2006). Inquiry learning: Teaching and assessing knowledge integration in science. *Science, 313,* 5790, 1049-50.

11. Schneider, M., & Stern, E. (2009). The inverse relation of addition and subtraction: A knowledge integration perspective. *Mathematical Thinking and Learning*, 11, 92-101.

12. Slotta, J. D., & Linn, M. C. (2009). *WISE science: Web-based inquiry in the classroom*. New York: Teachers College Press.

13. The Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher, 32*(1), 5-8.

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