120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #6591

Integrating K-12 Engineering and Science: Balancing Inquiry, Design, Standards and Classroom Realities

Dr. Marion Usselman, Georgia Institute of Technology

Marion Usselman is Associate Director for Federal Outreach and Research for Georgia Tech's Center for Education Integrating Science, Mathematics and Computing (CEISMC). She has been with CEISMC since 1996 developing and managing university-K-12 educational partnership programs and assisting Georgia Tech faculty in creating K-12 educational outreach initiatives. Before coming to CEISMC, Marion earned her Ph.D. in Biophysics from the Johns Hopkins University and taught biology at the University of North Carolina at Charlotte.

Mike Ryan, Georgia Institute of Technology
Mr. Jeffrey H Rosen, Georgia Tech - CEISMC

After fourteen years in the K-12 classroom teaching mathematics and engineering, Rosen took a position as program director at CEISMC. Since starting, Rosen has published numerous papers on using robotics as tool for instruction and on how to manage robotics competition to increase student interest and engagement in STEM. Rosen contributed a chapter to the book Robotics in K-12 Education on the FLL program model we developed that provides a benefit to student involvement in STEM. Rosen is involved in two NSF-funded research projects that use engineering design and robotics in STEM education. The NSF projects are SLIDER:Science Learning Integrating Design, Engineering, and Robotics and the recently awarded AMP-IT-UP:Advanced Manufacturing and Prototyping Integrating Technology to Unlock Potential.

Mr. Fred Stillwell, Georgia Tech - CEISMC

Fred Stillwell is a program director for Georgia Tech's Center for Education Integrating Science, Mathematics and Computing (CEISMC.) He recently joined CEISMC after a 20-year career in the Cobb County, Georgia schools, most recently at East Cobb Middle School in Marietta, Georgia. At East Cobb, Mr. Stillwell developed and taught an integrated science, technology, engineering, and mathematics (STEM) course as well as mentoring robotics and other engineering teams in various competitions including FIRST Lego League and the FIRST Tech Challenge. Current projects include developing an integrated Robotics and Engineering course funded through Federal Race To the Top funds and the NSF project: AMP-IT-UP: Advanced Manufacturing and Prototyping Integrating Technology to Unlock Potential.

Mr. Norman F. Robinson III, Georgia Institute of Technology

Norman Robinson has been teaching STEM for seventeen years and is currently serving as an education outreach manager for the Center for Education Integrating Science, Mathematics and Computing (CEISMC). Prior to my service began at CEISMC in June 2011, Robinson served as a STEM Magnet Mathematics teacher for Marietta STEM Middle School for two years. Robinson went to Marietta Middle School after working seven years as an Aerospace Education specialist for the Aerospace Education Services Project for NASA, based at NASA Langley Research Center and NASA Glenn Research Center. Robinson's career in education started in Greenville, SC teaching mathematics at Tanglewood Middle School and Riverside High School for seven years beginning in 1995. Currently, Robinson is a student in the Doctoral Program for Teaching and Learning - Mathematics Education at Georgia State University. Robinson earned a master of science degree in Natural and Applied Sciences with a concentration in Aviation Sciences from Oklahoma State University and a bachelor of science degree in Mathematics from Tennessee Technological University.

Dr. Brian Douglas Gane, Georgia Institute of Technology

Dr. Brian Gane is a postdoctoral fellow at the Center for Education Integrating Science, Mathematics, and Computing (CEISMC) at the Georgia Institute of Technology. Dr. Gane's research focuses on skill acquisition, STEM education, and assessment & modeling.

Sabrina Grossman, Georgia Tech: Center for Integrating Science, Math, and Computing

Integrating K-12 Engineering and Science:
Balancing Inquiry, Design, Standards and Classroom Realities

Introduction

The new Framework for K-12 Science Education[1], developed by the National Academy of Sciences, proposes markedly increasing the profile of engineering practices and concepts within the domain of K-12 science education. Concurrently, there is also a move to increase the visibility and rigor of the science and mathematics concepts that underlie activities taught in K-12 engineering/technology classes. And in all areas there is a push to increase the level of experiential and constructivist learning. The challenge for developers of instructional materials for K-12 education, both for core science classes as well as engineering/technology classes, is to create educational experiences where students learn the disciplinary concepts and practices mandated by state and national standards, while concurrently exposing students to important concepts from other domains and maximizing the experiential nature of the student explorations. To be effective and sustainable, the curriculum also needs to be mindful of the realities and limitations inherent in our modern system of schools: accountability pressures, regular benchmark testing of students, large classes, ranges in teacher pedagogical content knowledge, and the pervasiveness of annual standardized testing.

The Georgia Institute of Technology currently has multiple large sponsored programs that require the development of curricula for 8th grade physical science and 8th grade engineering and technology courses. The curricula need to align with the Next Generation Science Standards, meet state curriculum standards, and be implementable in regular public school classrooms. Our team, consisting of curriculum developers, educational researchers, and classroom teachers, is developing curricula through iterative design and implementation cycles and will be assessing the eventual impact on student learning in different populations and under different implementation conditions. Before we can even ask the question about student outcomes, however, we need to design curriculum materials that effectively meet the criteria and accommodate the constraints of real classrooms and real teachers – materials that can be implemented by teachers with at least a modicum of fidelity. This paper addresses the important issues of how much open inquiry or free design can be realistically implemented, and the extent that science, math and engineering can be integrated across core curricula that must, first and foremost, address specific content standards.

Contexts for Research

This research is drawn from two large sponsored programs—one is *Science Learning Integrating Design, Engineering and Robotics* (SLIDER), a 5-year NSF DRK-12 project that was funded in 2009, and the other is a *Robotics and Engineering Course* (REC) development project funded by the Georgia Department of Education through the Georgia Race to the Top (RT^3) award. Both projects strive to integrate the STEM fields in the 8th grade, but they do so within different academic domains. SLIDER uses LEGO NXT robotics and Project-Based Learning (PBL) to teach 8th grade physical science, and the RT^3 REC project integrates and reinforces science and math concepts within 8th grade Engineering and Technology connections classes using LEGO robotics, data-logging, and rapid prototyping with 3D printers. Both projects are developing curriculum materials, working closely with teachers for extended periods of time to help them develop the skills necessary for successful implementation, collecting formative data during pilot testing with teachers and students, and iteratively redesigning the materials based on the formative data. Each project also began the curriculum development process aiming to maximize both the level of inquiry and engineering design experienced by students, and the degree of integration of the STEM content. They also both chose the LEGO Mindstorm NXT to be the manipulative and primary vehicle for engineering design, as it was well documented to be "easy" enough for 8th grade students to use and has a reputation as being an engaging hook for students. While these projects operate in similar spaces and target congruent goals, there are important differences between them, as well.

The SLIDER curriculum builds upon the foundation developed by Kolodner et. al. as part of the NSF-supported Learning by Design (LBD) project[2] , which subsequently developed into the curriculum model published as the *Project-Based Inquiry Science* (PBIS) series for middle school science instruction[3]. PBIS was the result of a collaboration between science education and learning sciences researchers at the University of Michigan, Northwestern University, and the Georgia Institute of Technology. PBIS is a unique project-based inquiry learning approach to middle school science education founded in constructivist learning theory that aims to address the social and cognitive aspects of learning[2]. It incorporates the cognitive model of case-based reasoning where students learn from the lessons they formulated during previous experiences[4]. Students, working with a design artifact, attempt to solve a problem or meet a challenge. Over the course of a curriculum unit students redesign the artifact or device to meet the criteria and constraints of the design problem. In SLIDER, the lessons (bundled and sequenced as *Learning Sets*) each require approximately 10-15 days of instructional time in standard 50-60 minute classes. The final physical science curriculum will consist of 5-7 Learning Sets, and will cover the majority of the physics-based content standards. Teachers in the program are "regular" middle school science teachers who, with one exception, were not previously trained in PBL.

The RT^3 REC project originated through a local initiative to develop an integrated 8th grade STEM course that could be offered in parallel to the science and math core courses as part of the engineering and technology track of the Career, Technical and Agricultural Education (CTAE) pathway. CTAE courses in middle school are offered as elective *Connections Courses* that last for nine weeks. The 9-week RT^3 Robotics and Engineering course presents students with a design challenge that relies heavily on applied mathematics and science concepts. Students must learn STEM content, and then design (using *SolidWorks* 3-D design software) and manufacture (using a 3-D printer) a new LEGO-compatible plastic part that will enable their LEGO NXT robot to complete the challenge. Students are generally randomly assigned to the course, and the teachers are CTAE teachers with varying levels of science and mathematics understanding. Though some of the teachers come from traditional shop class backgrounds and have experience with "hands-on" instruction, most have never taught using either PBL or inquiry pedagogy.

Experiential Learning and Design

The level of experiential learning in science curricula is generally conceptualized as "levels of inquiry". A common scale of inquiry is shown below[5,6].

1. ***Confirmation Inquiry**—Students confirm a principle through an activity when the results are known in advance.*
2. ***Structured Inquiry**—Students investigate a teacher-presented question through a prescribed procedure.*
3. ***Guided Inquiry**—Students investigate a teacher-presented question using student designed/selected procedures.*
4. ***Open Inquiry**—Students investigate questions that are student formulated through student designed/selected procedures.*

Likewise, Daly, Adams and Bodner (2012) have developed the following somewhat hierarchical categories of engineering design[7].

1. ***Evidence-Based Decision-Making**—Design is finding and creating alternatives, then choosing among them through evidence-based decisions that lead to determining the best solution for a specific problem.*
2. ***Organized Translation**—Design is organized translation from an idea to a plan, product, or process that works in a given situation.*
3. ***Personal Synthesis**—Design is personal synthesis of aspects of previous experiences, similar tasks, technical knowledge, and/or others' contributions to achieve a goal.*
4. ***Intentional Progression**—Design is dynamic intentional progression toward something that can be developed and built upon in the future within a context larger than the immediate task.*
5. ***Directed Creative Exploration**—Design is directed creative exploration to develop an outcome with value for others, guided and adapted by discoveries made during exploration.*
6. ***Freedom**—Design is freedom to create any of an endless number of possible outcomes that have never existed with meaning for others and/or oneself within flexible and fluid boundaries.*

In reviewing the two examples above and several other rubrics of inquiry and design there is an implicit assumption among reform movements that the more *open* the inquiry and *free* the design process, the better. Both SLIDER and the RT^3 REC project have sought to maximize the degree of experiential and constructivist learning in the curricula by incorporating as much open-ended inquiry and design as possible. In contrast to this, however, the constraints of modern schools and the requirement that students master defined and assessable disciplinary content mandate a level of scaffolding that is often inconsistent with open inquiry. The examples below explore the different curricular compromises that we have had to make when creating multi-week instructional units for science and engineering classes that encourage deep learning and increased student engagement, but that can also be realistically implemented in regular schools by regular teachers.

Research Methods: Design Experiments

The term *design experiments* (alternately referred to as *design-based research, design experimentation*, and *design-research*) refers to an educational research approach that aims to develop and test, within the operational environment, educational innovations (or interventions) that successfully embody, advance, and refine educational theories by elucidating the contextual constraints, moderating factors, and mediating variables that constrain or shape how the intervention is implemented and its effectiveness[8,9,10].

Design experiments may use a collection of methods including retrospective analysis of design choices, narrative accounts of design implementations, qualitative and quantitative data collection, and quasi-experimentation. Though the methods and environments may change, design experiments are marked by several key features: multiple designs are tested; successive designs emerge through iterative cycles of design, test, and revise; designs tests are conducted in the environment in which they will be used (e.g., in the classroom) with the myriad of extraneous variables present; design principles arise from (and test) educational theories; and the results of the design iterations should bring successful designs that advance educational theories by offering more specific statements about the factors involved in implementation and their implications for generalizability[8,10,11,12].

Our methodology and approach is similar to design experiments, most notably in that (a) our designs are tested in the operational environment and we readily acknowledge that enactments of curriculum are driven by contextual factors that cannot be eliminated and should, instead, be understood in order to provide meaningful data, and (b) we use multiple sources of data to iterate our design changes over multiple implementations.

In SLIDER and the RT^3 REC projects, successive curriculum redesigns are based on multiple sources of data and feedback: task analysis and research on science content learning, alpha-testing of the activities in the laboratory (without students), curriculum design with our teachers during professional development workshops, and pilot testing curriculum in authentic contexts (i.e., with our partner teachers implementing the curriculum in their classrooms). Instruments include design logs, classroom observation protocols, surveys, student artifacts, and knowledge assessments.

The demographics of the schools that are implementing the SLIDER and RT3 REC curricula are shown in Table 1. Individual class enrollment ranges from approximately 18 to 36 students, and class length varies from approximately 50 to 70 minutes. The background of the ten teachers who are implementing the curricula varies widely, from the traditional woodshop teacher, to the young graduate of Georgia Tech, to the re-purposed social studies teacher, to the highly experienced science PBL practitioner—in short, it is a good cross-section of likely middle school STEM teachers, all of whom bring with them differing strengths and weaknesses.

Table 1—School Demographics								
	School	**# Students**	**% Free/reduced lunch**	**% White**	**% Black**	**% Hispanic**	**% Students w/ Disabilities**	**% Limited English**
SLIDER	1	662	80	44	48	4	15	2
	2	1305	65	26	50	17	12	8
	3	1185	16	64	17	8	11	2
RT^3	4	1329	92	5	24	60	11	22
	5	475	73	45	47	5	9	1
	6	544	88	0	99	1	7	0
	7	873	39	39	50	5	7	0

Examples of Iterative Redesign of Curriculum—

Moving along the Inquiry and Design Continuum.

Based on formative data collected during curriculum development and piloting, both the SLIDER and RT3 REC projects have been forced to decrease the amount of open-ended inquiry and design, and instead provide a more scaffolded learning experience than initially planned. Examples of these compromises are given below.

1. The SLIDER Curriculum.

The PBIS series promotes the use of a “Launcher” unit at the start of the school year that introduces common classroom inquiry practices, builds science process skills, and establishes the classroom culture for the rest of the year[13]. Though it takes several weeks to implement, the PBIS launcher unit is very valuable and can substitute for the traditional unit on the “scientific method” that teachers often start with at the beginning of the school year.

Working with LEGO NXT adds a challenge for the launcher unit, as most students do not enter the class having any proficiency with either building or programming LEGO robots. In order to design from scratch with LEGO, students need time to develop these skills. Therefore the SLIDER physical science curriculum initially began with a launcher unit that, in addition to introducing critical science process skills and standard classroom procedures, provided a learning sequence to enable students to master simple LEGO build and programming skills.

Curriculum developers designed and tested the launcher unit in-house, and piloted it with teachers in a 1-week summer institute. Based on formative data from each test, the unit was iteratively redesigned for implementation in one school, with 3 teachers and 11 classrooms of 8th grade physical science students. The first half of the unit introduced the students to the LEGO NXT, familiarized them with the different pieces, challenged them to explore build techniques, and culminated with a simple design challenge. The second half introduced the basic concept of programming as a series of sequential instructions, took students through the basics of programming the LEGO NXT central processing brick, and culminated with a simple programming challenge. The entire launcher unit was designed to span 14-16 school days, depending upon implementation pace.

Halfway through the implementation of the SLIDER Launcher unit it became clear, based on classroom observations and teacher feedback, that in a physical science class that is required to meet defined curricular standards, and where robotic building and programming are definitely not part of those standards, there is not enough time for students to realistically master LEGO NXT build and programming skills. Teachers were under tremendous pressure to "get to the content" that would be tested on benchmark and national standardized tests —i.e. the science disciplinary core ideas. It also became clear that the activities that took the longest and were done in groups were the most problematic because they took substantially longer in large, chaotic classes than they did in pilot situations. We therefore cut short the classroom implementation, and the second half of the Learning Set, which taught LEGO programming skills, was not implemented at all with students in the school.

Based on data collected during the aborted implementation, we redesigned the curriculum, eliminating the Launcher unit as a separate entity, and decreasing the time spent on developing LEGO build skills, and eliminating programming instruction entirely. We incorporated all science process skills development and the remaining LEGO build skills acquisition into learning sets that concurrently focused on physical science disciplinary core ideas, and substantially increased the scaffolding within the learning sequences, particularly when students are building with LEGO. Without this scaffolding and support, activities that require significant LEGO building and programming are not realistically implementable with students who have not received explicit instruction and experience building and programming with LEGO.

This compromise, however, has a profound effect on the curriculum as a whole; without the Launcher unit students do not have a common competence level with using LEGO NXT as a manipulative and no experience programming with LEGO. As a result, later activities must be more tightly scaffolded and constrained. As an example, a later activity that initially required that students independently design a braking system for a standard LEGO NXT robotic vehicle (built by the students from build instructions) was modified so that now students build a standard brake and test different materials on the brake pad. They then redesign the brake pad to make it more effective by combining and designing with a mix of the materials available.

Because this is a core science class and science practices (not LEGO design and build skills) are the critical part of the standards, students design and execute their own experimental procedures, but the LEGO builds have to be tightly controlled. We are maintaining the level of science inquiry at the "Guided Inquiry" level, but the engineering design is a scaffolded "Evidence Based Decision Making" process, not "Directed Creative Exploration". Additionally, later units could not require that students independently program the LEGO NXT. For instance, in the brake design activity the curriculum could not be designed to allow students to test the effect of increasing the power applied to the brake or experimenting with different timing delays.

2. RT^3 Curriculum

The 9-week RT3 REC curriculum begins with a challenge that requires students to first explore an issue through scientific observation, then model a LEGO NXT-compatible part using a subset of SolidWorks tools, print the part on a 3-D printer, test it, iterate on the design, retest and present the final version to the class. The time limitations present in the SLIDER classes are also very evident in the REC classes. Since the goal of the REC is to have students experience a data-driven engineering design project, not to just learn how to build and program LEGO robots, the curriculum designers in this project have had to make many of the same compromises described above. These include providing students with LEGO build instructions and downloadable LEGO programs and creating learning sequences where students redesign existing components using fairly tightly controlled procedures rather than designing freely from basic component parts. These curriculum design decisions were made because of time and materials management constraints and also because of the teachers' lack of expertise in engineering design, 3-D modeling, robotics and often basic classroom management.

The REC curriculum designers have also had to iteratively simplify the activities, decreasing the degrees of freedom available to the students in multiple realms. For example, one REC course focuses on biomechanics. Students initially observed the locomotion of "Hex Bugs"—mechanical bugs that are readily available and that vary in number of legs, types of gait, speed of locomotion, body shape, and color. These activities worked well in pre-testing, and when piloted with teachers in the summer. However because of the bugs' multiple different designs, the 8th grade students could not focus on the one factor that would be crucial to their later design challenge—namely how different types of feet interacted with different surfaces. In the next iteration the curriculum designers created a standard LEGO NXT 6-legged Bot that enabled teachers to bring into focus the foot, friction, and the forces between the foot and the surface, and to make explicit connections between the activity and the science, math and engineering concepts.

Students in the biomechanics course were initially going to design a whole leg and foot assembly for the NXT Bot using SolidWorks. Alpha testing revealed that was too difficult given the time constraints of the course. Students instead now redesign a basic template of a foot that has been pre-designed in SolidWorks. 3-D modeling proponents have complained that this eliminates too many degrees of freedom of design, however it enables the students to produce a product within the time available, allowing for testing and iterations on the design. We made the decision that it is more important for students to more thoroughly experience the parts of the engineering design cycle that include testing, collecting data, and iterating on the design—all skills that support the core math and science instruction--rather than to provide students with a freer design challenge.

Integrating science and engineering.

The concept of integrating science and engineering concepts in order to more effectively teach both subjects is certainly not new. Kolodner et. al. created NSF-sponsored curricula that used engineering concepts and an engineering design cycle to teach middle school science starting in 1996[14]. However this concept of curricular integration has gained more traction in recent years: "Integrated STEM" education is currently talked about in the national press as one of the possible solutions to our national STEM education challenges; the new Framework for K-12 Science Education explicitly includes engineering practices and core concepts within the domain of science education; and the Next Generation Science Standards will make explicit that science teachers should be including engineering concepts alongside the scientific ones. How this will be done has yet to be defined, and the success will ultimately depend upon the availability of curriculum materials that are implementable in actual schools, not just in the abstract. As stated in the Framework for K-12 Science Education[15],

> *While standards typically outline the goals of learning, curricula set forth the more specific means—materials, tasks, discussions, representations—to be used to achieve those goals.*

The National Academy of Engineering, in its report debating standards for K-12 engineering education[16], emphasized the current lack of understanding about how this integration should be done, and included in the recommendations for future research the following questions:

> *What are the most important synergies in the learning and teaching of engineering and mathematics, science, technology, and other subjects?*

And

> *What are the most important considerations in designing materials, programs, assessments, and other educator professional development that engage all learners, including those historically underrepresented in engineering?*

Both SLIDER and the RT^3 REC design project have been exploring these questions in challenging, but typical, school settings—the SLIDER project for three years within the science core classes, and the RT^3 REC for one year within the engineering and technology elective classes. Below are the lessons learned thus far from designing and implementing curricula that explicitly integrate science and engineering.

1) Integrating engineering within the science classroom

When working in a core science classroom, the science practices and core concepts outlined by the state educational standards have to be the number one priority. Schools and individual teachers are constantly, and often harshly, judged on the basis of how students perform on the state's accountability measures. When faced with the severe time limitations present in most science classrooms, engineering concepts that are not closely aligned with the science ones are the first to go. The SLIDER curriculum design team has worked hard to maintain as much engineering as possible in the physical science curriculum. However as described above, in the end it is more important to maintain a high level of focus on science inquiry, practice, and conceptual understanding in the classroom than it is to maximize the freedom of the engineering design experience.

The Framework for K-12 Science Education describes the differences between science and engineering practices that are, on the surface, rather analogous. It is not difficult to envision how activities within an engineering challenge can ensure that students develop models, plan and carry out investigations, analyze and interpret data, use math and computational thinking, engage in argument from evidence, and obtain, evaluate and communicate information—all of which are core scientific practices. However whereas engineers ask questions and define problems that should lead to a concrete solution to a societal problem, scientists seek to understand why something is happening, and instead of designing solutions, they construct scientific explanations to explain the phenomenon. Within the science classroom, it is crucial that students spend ample time grappling with the underlying scientific concepts and puzzling over why, scientifically, something is happening, not just designing a solution to an engineering challenge. Ultimately the goal in physical science is not for students to learn how to build and program LEGO robots to enable them to solve engineering problems, even if those activities naturally demonstrate physical science concepts. Every engineering challenge and LEGO build included in the curriculum must predictably and explicitly lead the students to a deeper understanding of a specific scientific concept outlined in the science standards. In the end, when time is a constraint, the emphasis in the learning sequence must be on ensuring that students construct proper scientific explanations that demonstrate that they have mastered the underlying science concepts, not that they successfully design an engineering solution or master an engineering skill.

2. Integrating science within the engineering classroom

We, along with many others, promote increasing the prominence of math and science concepts within middle and high school engineering and technology classes. It is our hope that engaging students in compelling engineering scenarios within elective engineering classes will help them understand the importance of learning the math and science skills that are the foundation of engineering (and are necessary for high school graduation).

The RT^3 Robotics and Engineering course has been designed to explicitly support and enhance grade-level math and science skills. The 8th grade biomechanics course highlights the physical science concepts of balanced/unbalanced forces and friction by challenging students to design robotic feet that enable the robot to move effectively on different surfaces. In the initial versions of the curriculum, teachers would deliver some direct instruction about forces and friction at appropriate times in the learning sequence. Unfortunately, technology teachers' science skills are often weak, and in the professional development summer institute it became clear that the majority didn't have the requisite knowledge to deliver actual science instruction. Like in the science class, there is also a defined set of engineering and technology standards that must be covered and very real time constraints. Since one of the major goals of the course is that students actually design and manufacture a solution to an engineering problem, they do not have the time to grapple with constructing good scientific explanations for the observed phenomena. Instead, the curriculum now includes activities that enable students to *experience* the science concepts in ways that support instruction in the science classes, and science explanatory sheets are included to assist teachers in pointing out the underlying science. Ultimately, however, the actual science concepts must be taught to mastery in the science class, not the engineering class.

Conclusions

Both the SLIDER and RT^3 REC curriculum development projects are being led by curriculum developers who have spent many years teaching K-12 science, math, and engineering and who themselves, when in the classroom, pushed the pedagogical envelope towards a highly experiential and integrated mode of instruction. They bring to the table a keen sense of what is possible in terms of student engagement and learning when lessons are taught in reasonably controlled environments by inspired and highly knowledgeable teachers who are not under tremendous accountability stresses. Of our seven schools and ten teachers, only one teacher's classrooms fit that description, and the students in that teacher's classes will do well on standardized exams regardless of which curriculum is used. The real challenge is how to create engaging and effective science and engineering curricula that can be implemented in classrooms that better fit the typical situation found in our nation's schools. One can wish away those somewhat dysfunctional classroom realities, but if we want to engage all learners, especially those traditionally underrepresented in STEM and who disproportionately attend the more challenging schools, we need to be willing to honestly address reality, and make concessions in curriculum design. In the end, the classroom realities and accountability pressures related to state educational standards need to be fully taken into account and accommodated. Otherwise the pedagogically sound, highly experiential, and thoughtfully integrated curriculum will never be enacted with enough fidelity to even begin to have an impact on the children who need it most.

Some of the contents of this presentation were developed under a grant from the U.S. Department of Education. However, those contents do not necessarily represent the U.S. Department of Education, and you should not assume endorsement by the Federal Government.

---

[1] The National Research Council (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: The National Academies Press.

[2] Kolodner, J.L., Camp, P.J., Crismond D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S., & Ryan, M. (2003). Problem-Based Learning Meets Case-Based Reasoning in the Middle-School Science Classroom: Putting Learning by Design™ into Practice. *Journal of the Learning Sciences*, Vol.12, No 4, pp. 495 – 548.

[3] Project-Based Inquiry Science. *It's About Time.* Herff Jones Education Division, NY.

[4] Kolodner, J.L. (1993). Case-Based Reasoning. San Mateo, CA.: Morgan Kaufmann.

[5] Bell, R.L., Smetana, L., & Binns, I. (2005) Simplifying Inquiry Instruction. The Science Teacher, October, 2005. 30-33

[6] Banchi, H. & Bell, R. (2008) The Many Levels of Inquiry. *Science and Children*, October 2008. 26-29

[7] Daly, S. R., Adams, R.S., & Bodner, G.M. (2012). What Does it Mean to Design? A Qualitative Investigation of Design Professionals' Experiences. *Journal of Engineering Education* 101(2). 187-219.

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

[9] Collins, A. (1992). Toward a design science of education. In E. Scanlon & T. O'Shea (Eds.), *New directions in educational technology* (pp. 15-22). New York: Springer-Verlag.

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

[11] Barab, S. (2006). Design-based research: A methodological toolkit for the learning scientist. In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 153-169). West Nyack, NY: Cambridge University Press.

[12] Cobb, P., Confrey, J., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher, 32*, 9-13.

[13] Kolodner, et. al. (2009) Diving Into Science. Project-Based Inquiry Science. *It's About Time.* Herff Jones Education Division, NY.

---

[14] *Learning by Design: Integrating and Enhancing the Middle School Math, Science and Technology Curricula*. NSF Award Number:9553583; Principal Investigator: Janet Kolodner; Co-Principal Investigator: Joanna Hornig-Fox, Mark Guzdial; Organization: Georgia Tech Research Corporation; NSF Organization: DRL Award Date: 05/15/1996;

[15] The National Research Council (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: The National Academies Press. pp. 10-4

[16] The National Academy of Engineering, Committee on Standards for K-12 Engineering Education. (2010) *Standards for K-12 Engineering Education?* Washington, DC: The National Academies Press.