AC 2011-1052: COMPARISON OF TWO CURRICULUM MODELS FOR MAPPING ENGINEERING CORE CONCEPTS TO EXISTING SCIENCE AND MATHEMATICS STANDARDS

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Comparison of Two Curriculum Models for Mapping Engineering Core Concepts to Existing Science and Mathematics Standards

Introduction

There is increasing national concern that many young people entering the workforce in the United States may be ill-equipped to handle the economic, technological, and environmental challenges of the high tech workplace[1,2]. The next generation labor force will need to be able to examine problems from a variety of contexts, create ideas from these contexts, analyze and synthesize information, and work collaboratively with a diverse set of colleagues – traits that are emphasized in the ABET engineering accreditation criteria[3], but unfortunately are not effectively honed by our K-12 educational system. To be effective, learning experiences should, at once: 1) be designed to target content and skill learning standards, and 2) incorporate 21st century contexts that include ample technology so that the experiences are relevant and valued by current and future students.

The National Research Council, in collaboration with the American Association for the Advancement of Science, the National Science Teachers Association, and Achieve Inc. is leading a project to develop a “Conceptual Framework to Guide the Development of Next Generation Standards for K-12 Science Education”[4]. The draft Framework for New Science Education Standards, circulated in July, 2010, supports the increased use of inquiry and problem/project-based learning (PBL) as a means to improve science learning, and for the first time presents engineering disciplinary ideas and practices as integral to science learning and literacy. It leaves unresolved the question of how to incorporate engineering standards or core engineering concepts into a science curriculum that is already overly packed with existing science skills and content.

The National Academy of Engineering (NAE), itself part of the National Research Council, in 2010 independently published a report from the Committee on Standards for K-12 Engineering Education entitled “Standards for K-12 Engineering Education?”[5]. The committee concluded that while there is intriguing evidence that engaging students with engineering concepts in K-12 can “stimulate interest and improve learning in mathematics and science as well as improve understanding of engineering and technology”, they did not recommend the development of actual K-12 engineering standards at this time. The committee had four primary reasons for this conclusion, the last being “There are significant barriers to introducing stand-alone standards for an entirely new content area in a curriculum already burdened with learning goals in more established domains of study.”

The NAE committee issued a series of recommendation in its report, namely that 1) the engineering community establish a consensus on the core engineering ideas that are appropriate for K-12 students; 2) that federal organizations promote the development of K-12 engineering instructional materials; 3) that research be funded about the best ways to incorporate engineering core concepts into K-12 education; and 4) that research be funded to determine the impact of K-12 engineering educational reforms. As part of this discussion of K-12 engineering education we present in this paper the rationale behind a currently-funded NSF DR K-12 project. The goal of Georgia Tech’s Science Learning Integrating Design, Engineering and Robotics (SLIDER) Project is to design, implement, and study the effectiveness of a robotics, engineering design and

PBL-based 8th grade physical science curriculum. This paper includes the cognitive and theoretical basis for Project-based Inquiry Learning (PBIL) and uses a task-analysis methodology, drawn from the field of psychology, to compare two different types of physical science curriculum units with regards to their learning goals, pedagogical structure, and nature of engineering core concept coverage. We conclude with a strategy for designing standards-based inquiry curricula that promotes engineering core ideas within the context of existing physical science standards.

Engineering in K-12 Education

Educators and curriculum designers have frequently relied on engineering design challenges as a context for active learning and inquiry. In most cases, other than within actual pre-engineering or technology courses, the educational standards covered within these engineering-infused instructional units are core science or mathematics standards, taught in standard science and mathematics courses. This is illustrative of what the National Academy of Engineering and National Research Council refer to as the “mainline” reason for incorporating engineering concepts in K-12—i.e. to enhance the science and mathematics education for all students. This is in contrast to implementing engineering materials specifically to increase the engineering “pipeline” of workers.[6]

There is no universal consensus about which engineering concepts or skills are most important for K-12 students to learn, or which are most effective at engaging students in science and mathematics learning. The NAE K-12 standards committee reviewed eight papers that attempted to identify critical core engineering concepts. The five ideas that were identified by at least five of the papers as important (here labeled as Core Engineering Concepts (CECs)) were[7]:

- Doing or understanding design. (The only concept identified by all eight authors.)
- Making connections between engineering and science, technology, and mathematics.
- The relationship between engineering and society
- Constraints
- Communication

Other important CECs, identified by four authors each were systems thinking, optimization, modeling, and analysis.

The process of incorporating engineering concepts into non-engineering K-12 courses can take two different routes. The “infusion” tactic requires that engineering standards be specifically included within the standards of the other course from the start. For example, newly created standards for 8th grade physical science might include standards for understanding the principles of engineering design. The alternative route, called “mapping”, consists of “drawing attention explicitly to how and “where” core ideas from one discipline relate to the content of existing standards in another discipline”[8]. In this case, engineering design principles might be used by curriculum developers to help students learn the content covered by existing physical science standards, but the course would not include an actual engineering design standard. This latter strategy is at the core of the curriculum development component of the SLIDER DR K-12 Project, which is using engineering design and LEGO Mindstorm robotics, within a project-based inquiry learning context, to teach basic physical science content, and in the process, engage students in the core engineering concepts listed above.

As the SLIDER Project development team reviewed possible curriculum models that would integrate and map engineering core concepts, we identified two that represent possible paths: One rooted in engineering and one rooted in PBIL. What follows is an analysis of these two models and their approaches, highlighting their similarities and differences.

Sample Curriculum Models

Model 1--PBIS – A PBIL Approach for the Science Classroom

PBIL is a cognitive-apprenticeship approach with roots in medical school training[9,10]. In this approach, students work collaboratively to solve problems and learn in a group setting, as well as individually. Students encounter a challenge, problem or situation for which they must address and create solutions. The experience and context, by design, demands that students actually apply the science content knowledge and skills they learn in class.

In PBIL, students identify what they know, what they need to learn more about, plan how they will learn more, conduct research, and deliberate over the findings all together in an attempt to move through and solve the problem. Working together in groups allows students to share knowledge and to build off the ideas and knowledge of others. Through the nature of this collaborative setting, students often are in the position where they need to engage in articulation, justification, and explanation behaviors. PBIL promotes content learning and skills development because it focuses on the exchange of ideas and provides intrinsic motivation for students to seek content knowledge and conceptual understanding that help them solve problems or address challenges. Common among effective PBIL curricula and experiences is a focus on student-generated ideas, where students reflect on their actions and investigations to make new decisions and to improve conceptual understanding[11,12].

There is a large amount of research extolling the benefits of curriculum and learning experiences rooted in PBIL[13,14,15,16,17.] These studies have found that PBIL affords: more active learning of content; the development of problem-solving skills; increased ownership in learning; greater understanding of the nature of the scientific endeavor; more flexible thinking; improved collaboration skills; and opportunities for students to become STEM "experts".

Over the course of the past decade, a group of NSF-funded curriculum developers have crafted a particular brand of PBIL science curriculum that incorporates design as a central aspect of the learning experience. The *Project-Based Inquiry Science* (PBIS) series is 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 PBIL approach to middle school science education founded in constructivist learning theory that aims to address the social and cognitive aspects of learning[18]. It incorporates the cognitive model of case-based reasoning where students learn from the lessons they formulated during previous experiences[19]. Students, working with a design artifact, attempt to solve a problem or meet a challenge. Over the course of a curriculum unit, the artifact or device is redesigned by students to meet the criterion and constraints of the design problem.

Model 2—Hands-on Engineering Problems as a Vehicle for Integrating Science and Mathematics.

The Integrated Teaching and Learning's (ITL) Outreach Program at the University of Colorado at Boulder has created many high quality engineering-based curriculum units, lesson plans and individual activities that are included in the TeachEngineering.com digital library. These units, created by engineering graduate students and reviewed by engineering faculty, are user-friendly materials for K-12 teachers, designed to impact K-12 student' science and mathematics knowledge and their awareness of engineering as a possible career[20]. The designers have shown significantly higher learning gains in experimental groups using the ITL Program materials compared with control classrooms. The vision statement of the ITL Program, adapted from the National Academy of Engineering and National Research Council, is "*To create a K-12 learning community in which students, K-12 teachers and the College of Engineering and Applied Science explore, through hands-on doing, the role of engineering and innovation in everyday life. And, to appreciate and apply the art of engineering through designing and building solutions to meet the needs of society.*"[21]

Comparison of PBIS and ITL models of curriculum design

We chose to use PBIS as a model for mapping engineering standards onto science curricula. Because PBIS is based on a PBIL paradigm, it looks and feels different than more traditional approaches to science education. Although the PBIL effectively promotes learning and motivation, it also provides challenges to classroom implementation. In this section we compare two lessons between PBIS and ITL, in order to illustrate the similarities and differences of the two models.

For comparison we selected the "Just Plane Simple" lesson and the associated "Tools and Equipment, Part I" activity developed by the ITL Outreach Program and the "Learning Set 2: How Can a Machine Change a Force?" from Project-Based Inquiry Science (PBIS)[22]. We chose these lessons for three reasons. First, they illustrate the different approaches that ITL and PBIS take for teaching work, mechanical advantage (MA), and simple machines. Second, both lessons occur early in the overall curriculum unit; they are both the second lesson/learning set. Third, they use a similar activity: learners measure the force required to move a weight up an inclined plane. Although on the surface the actual hands-on activity used in each curriculum is similar, the method in which ITL and PBIS use the activity to achieve the learning objectives is different. Therefore, it illustrates some of the differences between the ITL and PBIS approaches.

Methodology

In order to systematically compare these curriculum units we first identified six dimensions that are important to instructional efficacy and delivery. These dimensions are based on variables that have received empirical support for affecting learning outcome and/or are important pragmatic considerations when implementing the curriculum: 1) learning objectives, 2) sequence of concepts, 3) learning tasks and cognitive activities, 4) time to implement, 5) modularity of units, and 6) reference to core engineering concepts.

After identifying these dimensions, we performed a task analysis on the ITL and PBIS lessons. The task analysis focused on the pedagogical goals of each curriculum (based on stated lesson objectives and the implied intention of the activities and examples) and the overall sequence of concepts within the curriculum. Additionally, we performed a cognitive walkthrough in which the activities of the student learner were documented and analyzed in terms of the cognitive processes being activated.

Dimensions to Compare ITL and PBIS

Learning Objectives

Below we present the science content learning objectives (as specified in the teaching materials) for the broader lesson and the specific inclined plane activity. With respect to the inclined plane activity, the critical point is not that these activities have different objectives in ITL and PBIS, but rather how these objectives serve the broader goals of the lesson and unit.

ITL--"Just Plane Simple" Lesson and "Tools & Equipment, Part 1" Activity

Goals of Lesson

- Explain how the inclined plane, wedge, and screw make work easier.
- Identify how the inclined plane, wedge, and screw are used in many familiar engineering systems today.
- Discuss the mechanical advantage of an inclined plane, wedge, and screw.

Goals of Activity

- Calculate the mechanical advantage of an inclined plane in two different ways.
- Explain why the concept of mechanical advantage is useful for engineers.

PBIS--"Learning Set 2: How Can a Machine Change a Force?"

Goals of Lesson

- When the forces exerted on an object are unbalanced, the speed and/or the direction of the object will change, otherwise there is no change in motion.
- There are six different simple machines all of which provide mechanical advantage: inclined plane, wedge, screw, wheel and axle, leveler, and pulley.
- Work only occurs when a force exerted on a moving object is applied in or opposite to the object's direction of motion.

Goals of Activity

- Machines provide mechanical advantage to assist in moving objects. Mechanical advantage is the trade-off between force and distance.

The focus of the ITL activity is on calculating MA (theoretical and actual). The conceptual definition of MA and its mathematical formula has been explained prior to the activity. After calculating the different MAs, learners are asked to explain why there might be differences (e.g. friction).

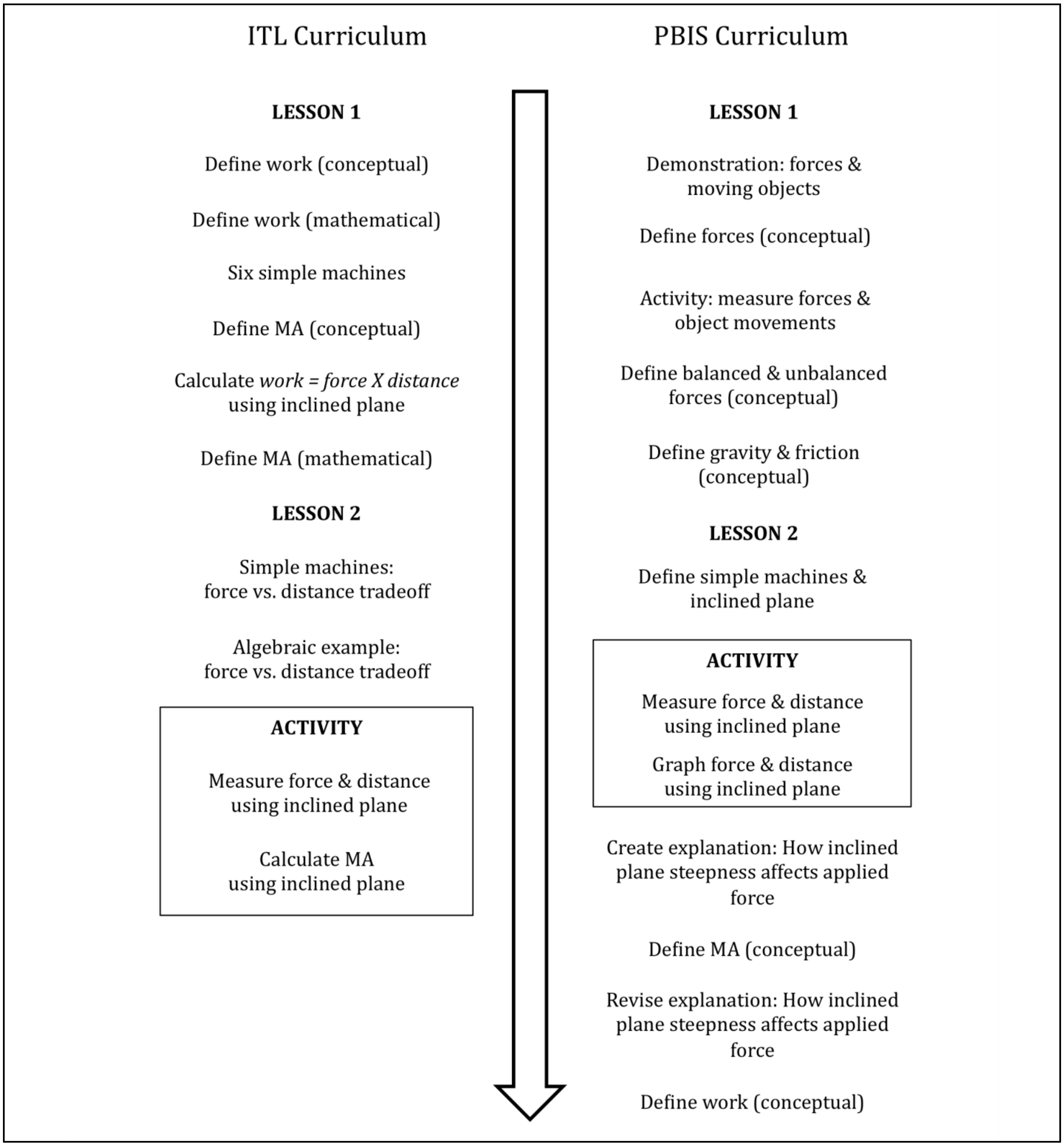
The focus of the PBIS activity is on having learners experience the trade-off between force and distance: as the steepness of the inclined plane decreases the distance increases and force decreases. The activity lets learners observe this relationship, collect and graph data illustrating this relationship, and then explain this relationship. The term mechanical advantage is not introduced until *after* completing these tasks. The MA concept is then presented in terms of a trade-off between force and distance, the relationship observed in the activity.

Sequence of Concepts

Creating an effective sequence of concepts requires considering the relationships between concepts. Moreover, developing scientific conceptual understanding is aided when concepts are sequenced such that they contradict learners' current mental models and integrating those new concepts lets learners explain their previous observations[23].

Figure 1 shows how the ITL and PBIS curricula sequence instruction on work and mechanical advantage. Two overarching differences between units arise from 1) the instructional paradigm and 2) the conceptual base used to unify the instruction.

Figure 1. Sequence of concepts related to work and MA in ITL and PBIS curricula.



First, the instructional paradigm for the ITL curriculum is similar to the "traditional" paradigm of teaching: define concepts, give the associated mathematical definition (i.e., formulas), and then have learners practice the math calculations. The PBIS curriculum is based on the PBIL paradigm: learners experience the phenomenon, complete a "think" activity in which they think through and/or discuss the phenomenon they just experienced, are introduced to the relevant concepts (often didactically, e.g., a lecture or reading), re-experience the phenomenon, and then complete another "think" activity to integrate their experiences and the scientific concepts. These differences in ITL versus PBIS sequences arise from differences in the "traditional" versus PBIL instruction paradigms.

Second, the two curricula differ in their conceptual base. ITL uses work and mechanical advantage as the base concept that runs through later instruction; simple and compound machines are understood in terms of mechanical advantage. PBIS uses forces as the concept that runs through all later explanations; work is understood in terms of forces and all simple machines are introduced in terms of changing applied forces. These differences are not inherent to the PBIL paradigm, but rather differences in the decisions made by instructional designers in ITL versus PBIS and reflect an engineering vs. science focus.

Learning Tasks and Cognitive Activities

Chi (2009) discussed how learning tasks can be designed into curricula in order to elicit greater and more in-depth cognitive processing, facilitating understanding[24]. Additionally, these activities can be designed to scaffold scientific thought using domain-appropriate reasoning[25].

Both ITL and PBIS share some learning tasks: lecture, read, measure forces and distances, record data, and answer engineering questions: in this case, about designing a ramp. In addition, ITL has some tasks that PBIS does not: calculate formulas, create explanations about whether 1) theoretical MA equals actual MA and 2) why these two measures might not be exactly equal.

Likewise, PBIS has some tasks that ITL does not. These tasks can be broken into "traditional" tasks (e.g., graph and analyze data, answer questions about simple machines), and PBIL-based tasks (e.g., write and discuss scientific questions for further investigation, update your project board, create your explanation worksheet, and communicate the design and solution effectiveness).

These PBIL-based tasks frequently use scaffolding to facilitate learners' use of scientific reasoning and engineering methods in order to use scientific concepts to explain observed data, to help learners monitor their own learning and identify future topics for investigations, to develop hypotheses, and engineer solutions to ill-defined problems. These tasks occur at the individual level (e.g., each learner answers questions individually), at the group level (e.g., three learners work together to design a solution), and at the class level (i.e., the class discusses what was learned and what still needs to be investigated).

We used Chi's (2009) taxonomy to classify these tasks in terms of passive, active, constructive, and interactive activities. Both ITL and PBIS use passive (e.g., lecture), active (e.g., measure forces), and constructive (e.g., explain why theoretical MA does not equal actual MA; create an explanation about the observed data from the inclined plane activity) activities. On the whole, PBIS has a greater proportion of constructive activities than ITL. Additionally, only PBIS uses interactive activities (e.g., a group decides which scientific questions warrant further investigation).

Interactive activities are hypothesized to be effective because the "learning dialogues" support construction of novel knowledge via dialogue between the participants. Due to the contribution of multiple participants the constructed knowledge is robust, including ideas from different participants. The resulting knowledge goes beyond what the learners would have been able to produce by himself or herself[26]. This is similar to scaffolding in that it allows the learners to develop understanding beyond what they could do without aid.

Time to Implement Curriculum

There is a large difference in time to implement curriculum between ITL and PBIS. These estimates are taken from the teacher resource guides. ITL is estimated to take 60 minutes to implement (20 minutes for the lesson; 40 minutes for the activity). In contrast, PBIS is estimated to take "6.5 periods, where a period is 40-50 minutes." Total time would therefore be approximately 300 minutes (5 hours).

Modularity of Units

One other primary difference between ITL and PBIS is the modularity of the units. The ITL lessons and activities are designed to be modular so that they are easy for a teacher to "drop-in" to their existing curricula. In contrast, the PBIS lessons and activities are not modular; they are designed within the context of an entire curriculum and larger project (i.e., the "big challenge"). As such, the lessons are not designed to be reordered or selectively excluded by the teachers.

Reference to Core Engineering Concepts

Finally, we reviewed explicit references to core engineering concepts in ITL and PBIS. We were interested in whether the concepts and activities were explicitly labeled as "engineering" concepts or practice. This might be important for increasing learners' interest in engineering as a discipline or profession; to increase interest in the discipline learners likely must engage with the concepts and understand that they are "engineering".

ITL frequently refers explicitly to engineering. Each lesson and activity has an "engineering connection" section that explains how the lesson/activity uses engineering applications to demonstrate science or math content, or how it uses engineering design. Teachers can use this information to make the link between the curriculum and engineering explicit for learners. Additionally, the ITL content and activities frequently explain how the scientific concepts are used by engineers ("*…engineers are continually thinking of ways we can do work easier — so that we can work smarter and not harder. One way engineers accomplish this is by designing machines that help make work easier and more efficient. More specifically, every machine today is comprised of one or more of the six known simple machines…*") and ask questions based on engineering design ("*If you were the engineer designing a ramp for a construction site to move a wheelbarrow a height of 30 meters, which inclined plane would you use? Why?*").

PBIS uses core engineering concepts throughout the activities (as explained later) but does not explicitly label them as "engineering" practice or explicitly connect the science to engineering.

PBIS does, however, provide applications of the science ("*Scientists have a very specific definition for machine. A machine changes the amount and/or direction of a force that can be applied to an object. This makes it easier to move things. At the construction site, you may have seen many large construction machines. ... Other machines make it easier for you to do everyday things….*") and asks applied questions based on design ("*You are designing a building. What type of ramp would you put on the entrance to the building to allow a person on a wheelchair the easiest access possible?"*). Nevertheless, these are not specifically labeled engineering and learners might not make the connection between these examples and the engineering discipline or profession.

Overall Comparison

In summary, PBIS uses a PBIL paradigm, focusing on experience before explanation and emphasizing constructive and interactive activities. In contrast, ITL provides explanations before the activity and uses active and constructive activities. Regarding implementation, ITL takes less time and can be used as modular units, whereas PBIS takes longer and is designed as en entire curriculum, not as individual units. Moreover, ITL, unlike PBIS, explicitly labels engineering concepts and vocabulary.

PBIS & Engineering Concepts and Standards

Since the PBIS curriculum does not explicitly focus on engineering concepts, how well does the curriculum model actually succeed in mapping core engineering ideas? Through the design of artifacts in PBIS units, students engage in the behaviors and activities of designers, engineers, and architects: they analyze a challenge, generate ideas to answer the challenge, investigate the science and math concepts governing the challenge, build or test models to obtain feedback and reflect, and then redesign the solution based on feedback to better meet the challenge. Figure 2 illustrates PBIS students' iterative engagement in design and investigation that helps students meet their design challenges.

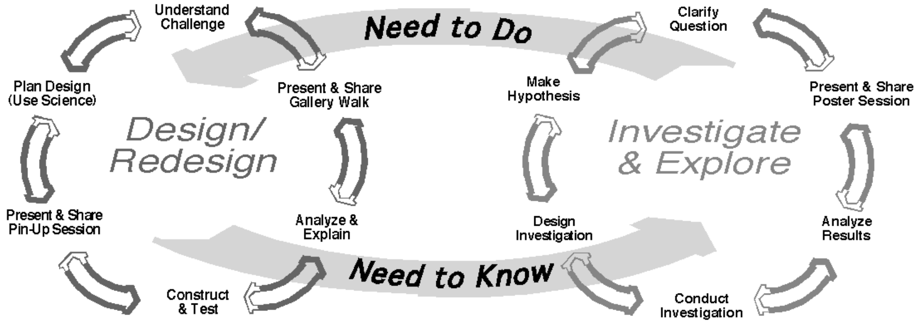


Figure 2: LBD Cycles of Activities (from Kolodner, Gray, and Fasse, 2003[27])

PBIS essentially employs two cycles of activities anchored by the contextualized challenge. The cycle has students identify what content knowledge and skills they need to learn. Students then complete investigations or research to gain that knowledge and skill, and then they attempt to apply it to their challenge. This application often raises more questions to investigate, or students realize they need to investigate the phenomena differently. They iteratively move back and forth between the investigation and design cycles until they are ready to provide a final answer or solution to the challenge.

Throughout a PBIS unit, students engage in several defined classroom protocols or activities known as *PBIS Practices*. The practices are facilitated by the teacher to move students effectively and with purpose through the cycles of learning. PBIS Practices are designed to help students productively engage in the hands-on activity and then reflect on that experience. They are intentionally designed to encourage reasoning that helps students connect abstract principles (e.g., Newton's Third Law) to the driving question or design statement (e.g., *make a balloon car that can travel over two steep hills while carrying a load*). These Practices help students design, create, collaborate, communicate, and develop and apply understanding during the unit. Practices are carried out similarly each time, so that the focus is on the content and outcome of the Practice. Table 1 provides a list of some the PBIS Practices, the purpose of each, and when they occur in the learning cycles illustrated in Figure 2. As we consider the prospect of mapping engineering standards and concepts across the SLIDER Project, Table 1 also describes opportunities in the PBIS framework to target the core engineering concepts (*CECs*) identified earlier.

Table 1: PBIS Practices

Project Board Update	Purpose	A forum for sharing what peers know, their ideas, and what they need to learn, and to keep track of class' progress and common knowledge. Usually in the form of a large wall poster or projected document, that iteratively is edited.
	Cycle Position	*Design*: Understand challenge *Investigate*: Clarify Question, Make Hypothesis, Analyze Results
	CECs	1) Doing or understanding design, 2) Making connections between engineering and science, technology, and math (STM), 3) The relationship between engineering and society, 4) Communication, and 5) Systems thinking
Mess About	Purpose	Exploration (in small groups) of materials or devices to identify phenomena, promote question asking, and see connections between science and the world; followed by *Project Board Update*
	Cycle Position	*Design*: Understand challenge
	CECs	1) Doing or understanding design, and 2) Constraints
Briefing	Purpose	Presentation of either plan, interim solution, or idea for final presentation to communicate conceptual understanding and justification; for peer review
	Cycle Position	*Design*: Plan Design, Present & Share *Investigate*: Design Investigation, Present & Share
	CECs	1) Doing or understanding design, 2) Constraints, 3) Communication, and 4) Modeling

Explore & Build and Test	Purpose	Execute a planned investigation or research activity to obtain data, observe behavior and/or identify trend (*Explore*); iteratively attempt to manipulate or redesign artifact as a solution to problem or challenge, testing performance against criteria. (*Build and Test*).
	Cycle Position	*Design*: Construct and Test *Investigate*: Conduct Investigation
	CECs	1) Doing or understanding design, 2) Making connections between engineering and science, technology, and math (STM), 3) The relationship between engineering and society, 4) Constraints, 5) Systems Thinking, 6) Optimization, 7) Modeling, and 8) Analysis
Investigation Expo & Solution Showcase	Purpose	Present procedures, results, and analysis of investigations for peer review (*Investigation Expo*); Present final design artifact for peer review and measure against challenge criteria (*Solution Showcase*).
	Cycle Position	*Design*: Present & Share *Investigate*: Analyze Results, Present & Share
	CECs	1) Doing or understanding design, 2) Making connections between engineering and science, technology, and math (STM), 3) The relationship between engineering and society, 4) Constraints, 5) Communication, 6) Systems Thinking, 7) Optimization, 8) Modeling, and 9) Analysis
Explain & Recommend	Purpose	Identify trends in data and behaviors of devices; connect scientific explanations so as to know when the trends apply; generate interim recommendations to others for solving the problem or answering the challenge.
	Cycle Position	*Design*: Analyze & Explain, Understand Challenge *Investigate*: Analyze Results, Present & Share
	CEC	1) Making connections between engineering and science, technology, and math (STM), 2) Communication, 3) Systems Thinking, 4) Optimization, and 5) Analysis

Conclusions

The fairly standardized system of school constrains teachers and administrators from providing additional classroom time for science and mathematics. Additionally, science and mathematics teachers are generally not well-versed in engineering concepts and might have difficulty teaching them outside the context of their domain. Therefore, mapping engineering concepts to existing standards-based science and math curricula, rather than infusing them from the beginning as independent standards, seems the most appropriate strategy for developing engineering understanding among students. As such, curriculum developers must review best practices and pedagogy in science education and look for ways to align and integrate engineering concepts. Materials like PBIS are appealing not only for reported learning and motivational outcomes, but also because it has a framework in place that would afford mapping CECs to standards-based science curricula.

Earlier we discussed and compared the ITL paradigm and learning experience to the PBIS paradigm and learning experience. The ITL approach is upfront and explicit with terms, concepts, vocabulary, and learning outcomes, both for science and engineering content. For example, students read about simple machine types, and they are told that simple machines can help engineers build complex machines that make work easier. Students then have an experience with a device that confirms these statements. In this way, ITL is hands-on and uses active and (some) constructive activities, but it does resemble more traditional methods of curriculum design and learner experience.

PBIS also has students engage in hands-on materials, however the paradigm and sequence of experience are not traditional. Additionally, PBIS activities focus on active, constructive, and interactive activities: students engage with projects or problems that challenge them to create or craft a solution. Students are not told what the outcome of their experience will be explicitly. Those outcomes are generated along the way throughout the experience. Students construct the knowledge the teacher wants them to learn by doing what scientists and engineers have done in the past or are still doing today. In PBIS they participate in a prescribed sequence that presents science and engineering concepts *after* they have experienced them in-person. For example, the idea of mechanical advantage is created through an experience that lets students see the underlying leverage each simple machine provides for the challenge they have been presented. Students construct the mechanical advantage principal by noticing and explaining the force-distance tradeoff during several investigations of simple machine types, prior to actually knowing or naming it, “mechanical advantage”.

A PBIS approach to learning requires more than one hands-on event per concept. It requires iteration and a teacher capable of focusing the class without giving away answers to questions the students have formulated and need to answer themselves. It requires that teachers recognize connections between concepts and challenges in order to make each experience's learning outcome explicit for students. This presents two interesting challenges for such curricula: 1) the time to complete this in-depth curriculum, and 2) the teaching skill level required to facilitate implementation. More research and development of curricula that inherently mitigates these obstacles is surely needed. That said, the opportunity this approach provides is alluring. PBIS's structure and suite of practices allow students to experience a phenomenon and make sense of it (in service to a goal or challenge) before they are told what it is and how it is supposed to work. When one reviews the PBIS structure and suite of practices, one can see how CECs can be discussed and *experienced* first-hand by students, who then can use this information and skill to make informed decisions about the contextualized challenges they are tackling. This is the promise of PBIS with regard to mapping CECs and developing engineering understanding in K-12.

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