AC 2010-1121: THE ENACTED CURRICULUM: A VIDEO BASED ANALYSIS

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The Enacted Curriculum: A Video Based Analysis of Instruction and Learning in High School Pre-Engineering Classrooms

Abstract

Engineering excellence serves as one of the primary vehicles for technological innovation, economic prosperity, national security, and advancements in public health. To address engineering preparation and appeal, technical education programs have emerged that provide hands-on, project-based curricula that focus on the integration of mathematics and science knowledge with engineering activities. Learning Sciences research emphasizes that integration of conceptual knowledge must be made explicit to learners to promote successful transfer of these ideas to novel problem-solving and design contexts.

In this study, we analyze the second foundation course in the *Project Lead the Way*™ sequence, *Principles of Engineering* ™. We found that while a significant portion of the instructors' time was spent on class management tasks, such as collecting worksheets and taking roll (non-instructional time), lecturing and tutoring took up the bulk of the class time. Only a small amount of time in class was spent on non-interactions between the instructor and students. Second, a greater proportion of the total instruction time was devoted to concepts than skills; moreover most concept instruction co-occurred with skills instruction. Lastly, over one third of the instruction linked mathematics skills and concepts to engineering skills and concepts. Explicit connections were made more often than implicit connections, though, occasionally, no connections were made between the mathematics being discussed and the engineering activity that was the focus of the lesson.

These analyses show greater presence of concepts, and more frequent explicit conceptual connections between math and engineering than observed in earlier analyses of *Introduction to Engineering*™*,* the first course in the *Project Lead the Way*™ program. Thus, our observations of the *Principles of Engineering*™ courses show several ways in which instruction may provide stronger support for learning, engagement and transfer than was evident in observations of the *Introduction to Engineering*™ course. This empirical research stands to identify where engineering education promotes the deep and well-integrated concepts and skills that can lead to the successful transfer of that knowledge throughout one's STEM education and conversely where the curriculum can be improved.

Introduction

The Intended, Enacted, Assessed and Learned Curriculum

Curriculum analyses can be divided into the study of intended, enacted, assessed, and learned curricula. The *intended curriculum* refers to the content of the course or program under investigation. For K-12 education, this generally includes the printed course materials and other resources, as well as national and state curriculum standards, which specify the grade-specific objectives for what each student must know and be able to do. The *enacted curriculum* refers to the specific content as it is taught by teachers and studied by students during the course of learning and instruction. The earliest work on assessing the enacted curriculum was done to create a dependent variable for use in research on teachers' content decisions[1] In contrast to the intended curriculum, the enacted curriculum is dynamic and varies from teacher to teacher, and even changes across classrooms taught by the same instructor, as the specific interactions vary with different students. Documenting the enacted curriculum is important because students generally learn what they are taught and what they spend time doing rather than what is intended[2]. For example, content of the enacted curriculum is a reliable predictor of student achievement gains[3,4]. Measures of the enacted curriculum can also be used to investigate the quality of instruction and curriculum implementation[5]. In this case we study the enacted curriculum to try to understand where explicit integration occurs, which in turn addresses some of the necessary pre-conditions that allow students to transfer knowledge to new tasks and to situations beyond the classroom. The enacted curriculum is interesting to study using video analysis because we can review what was actually taught to the students and compare it to the intended curriculum. (Teacher logs and self-report surveys have also been used as methods for obtaining information about the enacted instruction[6,7,8].

The *assessed curriculum* refers to the specific content that is tested and can differ drastically from the intended and enacted curricula. Tests are drafted by the federal government (thought instruments like NAEP, for example), individual states, districts, and the teachers themselves. The *learned curriculum* captures the actual changes in knowledge by the individual students, which reflects the notion that students can and often do learn more and less than offered in the instructional context.

In earlier studies, we analyzed the enacted curriculum of the first *Project Lead the Way*™ foundations course, *Introduction to Engineering Design*™. We found that (1) more of the instructor's time was spent on class management (non-instructional) tasks—especially collecting and grading team project work—than on any other classroom activity, (2) a greater proportion of the total observed instruction time was devoted to skills than to concepts, and (3) only a small fraction of instruction that linked math concepts to engineering coursework (science concepts were absent in these lessons) made those links explicit[9].

The Importance of Explicit Integration for Transfer

Transfer of learning or *knowledge transfer* refers to the ability of a learner to generalize what is learned from a particular instance and apply it to novel situations. Since it is not feasible that students can be exposed to every type of task and every situation in which their learning may apply, the ability to transfer knowledge is essential. While this may seem intuitive, the earliest studies of transfer document the limits of how transfer occurs[10,11]. These studies showed that while people may do well when tested on the specific content that they practiced, even seemingly small changes can thwart transfer. However, with regards to teaching and learning, there are several classroom techniques that can be used to improve knowledge transfer. Three categories of learning strategies "directly related to learning are rehearsal, organizing and elaboration" [12] as well as the use of examples or sample situations. These strategies are used differentially depending on the desired outcome. For most complex outcomes, such as the application of a skill or procedure, elaboration is needed, since "learners must make linkages between individual pieces of information" [12] in order to make sense of the bigger picture. Other studies suggest that it is the type of work students are asked to do that makes a difference in their ability to develop lifelong competencies in addition to transfer skills. For example Dunlap [13] notes that problem-centered instruction allows students to connect to a "real-world" context, promoting the student's ability to adapt and participate in change, make reasonable decisions in unfamiliar situations, appreciate other perspectives, collaborate as team members and be able to engage in self-directed learning and meta-cognition. Most importantly, problem based learning also has a positive impact on "knowledge and skill acquisition and transfer" [13].

Thus, we emphasize the need for instructors to use the intended curriculum in a way that explicitly connects mathematics to the engineering curriculum and allows students to explore examples and sample situations though problem centered instruction. In past studies, we have reviewed the intended curriculum of the *Project Lead the Way*™ foundations courses, including *Principles of Engineering*™ [14]. In this study, our main goal is to analyze the enacted (or taught) curriculum, allowing us, in some cases, to compare our findings to our previous work to further shed light on the teaching and learning of engineering at the high school level.

Research Questions

Analysis of the *enacted* curriculum provides an inherently rich account of what happens in the classroom, since the focus is on the student: his or her interactions with the teacher, with other students and with technology. This is especially important in applied course work, such as *Principles of Engineering*™, in which students are taught lessons that involve science and mathematics concepts and are expected to subsequently use those concepts in new ways to create engineering solutions. Two examples of these engineering solutions are the design, implementation and testing of ballistic devices and of load bearing bridges. In these cases, classroom observation provides a rich arena for understanding the teaching and learning transaction.

Project Lead the Way™ (PLTW) offers a four-year, pre-engineering high school curriculum, *Pathway to Engineering*™. Nationwide, approximately 3,500 schools use PLTW™. The sequence includes three foundations courses; *Introduction to Engineering Design*™, which we analyzed in previous work [9] is the first course. This course introduces students to what engineering is and what engineers do. *Principles of Engineering*™ is the second course, and is analyzed here. This course introduces students to projects that engineers work on. The last course in this sequence is *Digital Electronics*™ and we have not reviewed the enacted curriculum for this course. *Digital*

Electronics™ includes lessons in applied logic and extends the students' work into circuitry. In order to teach any of these courses, instructors must attend a two-week intensive summer training in which they learn the curriculum and how to teach it.

This paper reports on findings from quantitative and qualitative analyses of video data from five PLTW lessons from the second foundations course, *Principles of Engineering*™, as implemented in two urban high schools. The analyses were motivated by three research questions:

1. How is class time distributed between teacher-centered instruction, teacher-directed tutoring, student-directed collaboration, and non-instructional tasks? Further, since this is a project-focused curriculum, how do students work in-class to complete these projects?
2. What portion of class time is spent on concepts and skills that are central to STEM education (as determined by national and state standards)?
3. How frequently do we observe *explicit* integration of mathematics and science ideas in engineering activities and lessons?

Data and Methodology

We report here on findings from our mixed methods analysis of video data from five *Principles of Engineering*™ lessons on three separate days at two observation sites, both large urban high schools that offer several different PLTW courses. The lessons we observed covered two project areas, bridge building (2 lessons) and ballistic device construction (3 lessons).

First, the videotapes were digitized and entered into Transana[15] (see www.transana.org), a computer application for discourse analysis that integrates the video, transcript text and codes. Classroom sessions were segmented into clips, and clips were coded to reflect the points of interest noted in our research questions, in a manner similar to Nathan et al., 2009[9].

Coding Framework

Our coding framework delineates four dimensions:

A. *Instruction time* codes subdivide each class period based on how the instructor interacts with students. This information is reported for all 5 hours of instruction time.

B. *Project work time* provides data on how often students are working individually, with the instructor or within groups in order to complete the projects included in the PLTWcurriculum.

C. *Concepts* mark engagement with "big ideas" from STEM, such as: modeling in engineering; force and work in science; and algebra in mathematics. We separately note whether math concepts are explicitly integrated for students during instruction.

D. *Skills* address process-oriented tasks that are important for doing practical engineering work, such as problem solving and project management. We separately note whether math skills are explicitly integrated for students during instruction.

We discuss each dimension below to comment as necessary on the relevance of each to our research questions and to briefly describe each code.

Instructor's time

The instruction time code group allows us to characterize how the instructor allocates class time during lessons. This code is directly relevant to our first research question and stands to shed light on what a typical day of PLTW instruction in a *Principles in Engineering* ™ classroom "looks like." The codes and their descriptions for this data dimension are given in Table 1.

Table 1: Instructional Time Codes

Code	**Description**
Lecture	Teacher is engaged in large-group instruction, including lecture-style teaching and demos directed at all or nearly all of the students in the class.
Leading students	Teacher is following along with student discussion and occasionally offering information to help the student stay on track or come to a conclusion.
Tutorial	Teacher is engaged in one-on-one or small group tutorials, including teaching or reviewing of concepts as well as hands-on how-to's and troubleshooting.
Class management	Teacher is engaged in administrative, disciplinary, or other non-instructional tasks, including collecting homework, etc.
Non-instruction	Teacher is interacting with the students, but instruction is not happening.
Non-interaction	Teacher is not interacting with students and may be grading, doing preparation, conferring with colleagues, etc.

Project Work

Project work codes were developed to help give us more insight as to how students completed the hands-on portions of the PLTW curriculum. Since much of the project work done in this curriculum relies on resources available only in class, we felt that it was important to review how time devoted to project work was spent with the student as the reference point.

Table 2: Project Work Codes

Code	**Description**
Student works alone	The student is completing an aspect of the project work on his/her own.
Student/ Instructor	The student interacts directly with the instructor, who answers questions, provides feedback on written components, checks hands-on work, questions the student, etc.
Student/ Student	The student interacts directly with one or more other student in order to complete the project. The students may engage in tutoring one another, bouncing ideas off one another, or collaborating to problem solve.

Concepts and Skills

Concept codes identify segments of class time that revolve around the central organizing ideas from mathematics and engineering[16]. The individual codes in this group, shown in Table 3, were taken from mathematics standards recommended by the National Council Teachers of Mathematics (NCTM) for grades 9-12 as well as elements of the engineering design process. Additionally, in some cases we included codes that reflect important concepts identified in various scholarly[17], regulatory/professional[18,19], and popular[20] accounts of the study and practice of engineering. Lastly, some of the codes were derived from classroom observation itself.

Table 3: Concept Codes

Code	**Description**
Mathematics: Algebra	Understand patterns, relations, and functions; Represent and analyze mathematical situations and structures using algebraic symbols
Mathematics: Geometry	Analyze characteristics and properties of two- and three-dimensional geometric shapes and development of mathematical arguments about geometric relationships; Specify locations and descriptions of spatial relationships using coordinate geometry and other representational systems; Apply transformations and use symmetry to analyze mathematical situations
Mathematics: Measurement	Map out the measurable attributes of objects and the units, systems, and processes of measurement and application of appropriate techniques, tools, and formulas to determine measurements
Mathematics: Number	Understand numbers, ways of representing numbers, relationships among numbers, and number systems; Understand meanings of operations and how they relate to one another; Compute performed fluently and reasonable estimates made
Engineering: Design Basis	Emphasis on the importance of creating a pre-specified "statement of the problem" or system requirements.

Engineering: Feedback	The incorporation of real-time control systems for measuring and responding to changes in state. Not to be confused with feedback on how the product works (either from users or during the testing and evaluation design stage).
Engineering: Functional Analysis	Determine how a system works, and what the purpose of each element of the engineered system is.
Engineering: Modeling	A representation of a design or system. Can be "literal" (as in a physical or electronic one-, two-, or three-dimensional model of the design itself) or symbolic (as in when equations, graphs, or schematics represent interesting aspect of the design). Sometimes the model is explicitly coupled to an analysis or testing/evaluation task.
Engineering: Re-Engineering	Improvement upon an existing design. This may require "reverse-engineering" if design artifacts like drawings and models are not available.
Engineering: Structural Analysis	Determine the strength of materials in a structure based on empirical testing or calculation of forces/stresses and understand the conditions necessary to conduct this analysis.

Skills codes are distinct from concept codes in that they focus on process-based procedures which allow the student to perform actions or apply learned concepts. Skills are important for engineering learning and competency[21]. Often, a student must understand an underlying concept in order to be proficient in a certain skill – for instance, in order to skillfully hit a target using a ballistic device, a student must understand some of the interrelated concepts from geometry, physics and measurement, among other things. Often the math skills are captured in the NCTM's [22] *process* standards.

Table 4: Skill Codes

Code	**Description**
Mathematics: Communication	Organize and consolidate mathematical thinking through coherent and clear communication to peers, teachers, and others; Analyze and evaluate the mathematical thinking and strategies of others; Use the language of mathematics to express mathematical ideas precisely.
Mathematics: Connections	Recognize and use connections among mathematical ideas; Understand how mathematical ideas build on one another to produce a coherent whole; Recognize and apply mathematics in contexts outside of mathematics.
Mathematics: Problem Solving	Solve problems that arise in mathematics and in other contexts, using appropriate strategies.
Mathematics: Reasoning	Develop, select and evaluate mathematical arguments and proofs.

Mathematics: Representation	Create and use representations to organize, record, and communicate mathematical ideas; Use representations to model and interpret physical, social, and mathematical phenomena.
Engineering: Understanding Constraints	Ability to keep in mind parameters of the project while creating a solution.
Engineering: Creating Hypotheses	Generate an idea for testing based on knowledge of what might work (from math or physics, for example, or even other things that exist - a bridge in your neighborhood, something found in nature or even experience).
Engineering: Project Management	Figure out what must be done at certain time points in order to meet a deadline.
Engineering: Use of Software for Design	Use of computer aided tools for creating and modeling the project.

Explicit Integration of Concepts and Skills

We applied an additional code to any video clip coded for math skills or concepts indicating whether that concept was explicitly integrated into the surrounding engineering or technology lesson or implicitly imbedded. *Explicit integration* is defined as any instance wherein the materials specifically point to a mathematics principle, law, or formula, and depict how it is used to carry out or understand an engineering concept, task or skill[14]. Learning skills and new concepts requires a conceptual basis that is specifically pointed out to the student for it to be impactful[23]. Furthermore, a lack of integration between one's prior knowledge and new curriculum materials is problematic given the Learning Science research that emphasizes the importance of explicit integration of conceptual knowledge for successful transfer of that knowledge to novel applications or new situations [23,24,25]. Implicitly embedded concepts and skills are those in which the conceptual basis for understanding how mathematics is used for engineering is folded into the lesson, but not specifically pointed out by the instructor. Occasionally, but rarely, students will discover these connections on their own, even though they may be readily apparent to teachers, curriculum designers, and other content experts. Lastly, if there were no connections (either implicit or explicit) made between mathematics and engineering, these instances were labeled as such (i.e., no connections).

Research Procedure

A single researcher did all of the preliminary clipping and coding of the five videotaped lessons. Reliability of many of these codes was previously established using multiple coders and computing inter-rater reliability[9]. Clips were first created separately to identify how instruction time was used (in order to code the entire length of the class time). This allowed the researcher to watch the full length of each class session. Next, each lesson was reviewed for the use of mathematics and engineering skills and concepts. The researcher made every attempt to try to isolate single events that captured concepts, skills or interactions whenever possible. However, mutually exclusive coding for single teaching and learning events was not always possible -- sometimes two or more interactions occurred in a single clip because of their intertwined nature. The main mechanism for establishing reliability was a review by a second researcher, including discussions surrounding various codes and how they were applied, allowing consensus to be built around the application of the coding scheme. Secondly, the primary researcher reviewed clips and codes over several passes to ensure that each code was applied properly.

Results and Conclusions

Our analysis of the video data resulted in four main findings related to our three research questions.

With regards to how class time is distributed, we found that while a significant portion of the instructors' time (23%) was spent on class management tasks such as collecting worksheets and taking roll (non-instructional time), the bulk of the class time was taken up with lecturing (36.5%) and tutoring (33.6%). This is quite different from comparable analyses of how class time was apportioned during the first course in the PLTW sequence, *Introduction to Engineering Design*™ (IED)[9]. Analysis of IED classes showed that class management and non-instructional tasks took up close to 60% of the class time, limiting the amount of class time that could be spent on the engineering curriculum.

Second, with regard to time devoted to concepts and skills central to STEM education, a greater proportion of the total instruction time for *Principles of Engineering*™ was devoted to mathematics and engineering concepts (40.7%) than skills (36.1%), illustrating a greater focus on helping students understand the underlying reasons why skills such as calculations, problem solving and the use of computer programs work.

However, it is also true that students can master a particular skill without true understanding of underlying concepts -- for instance, a student might be able to "dimension" members of a bridge using CAD software tools but may not understand the geometry concepts that underlie the software output. To identify this distinction we also looked at how often concept instruction co-occurred with skills instruction. Concepts and skills were presented in tandem 46.7% of the time, indicating a clear commitment toward linking skills and concepts in both engineering and mathematics. This linkage is consistent with the IED course, where 69% of skills and concepts co-occurred.

Third, we are interested in understanding how often students were presented with the connections between mathematics and engineering. We found that over three quarters (77%) of the instruction linked mathematics skills and concepts to engineering skills and concepts. Explicit connections were made more often than implicit connections (51.8% versus 25.2%), though, occasionally, no connections were made between mathematics and engineering (18.9%). Compared to our earlier analysis of the entry-level IED course, where 29% of the material was explicitly connected, this course showed almost twice as much explicit connection, a remarkable difference. When materials are explicitly connected, students are better able to transfer the knowledge they learn in the classroom to novel settings. Therefore, the data from the enacted curriculum reviewed in this paper implies that this curriculum is more effective at preparing students for knowledge transfer than the previous PLTW curriculum we reviewed.

Enactment of Curriculum Results in Varied Class Time Proportions

Figure 1 shows wild variation in the way in which class time is spent. This is primarily due to the differences in the day to day work related to a project-based curriculum. Please note that these five lessons represent a small fraction of the PLTW *Principles of Engineering* ™ curriculum, so what we have here are merely snapshots. Subsequent studies with a greater number of classroom observations will ultimately be needed to establish greater generalizability of these findings.

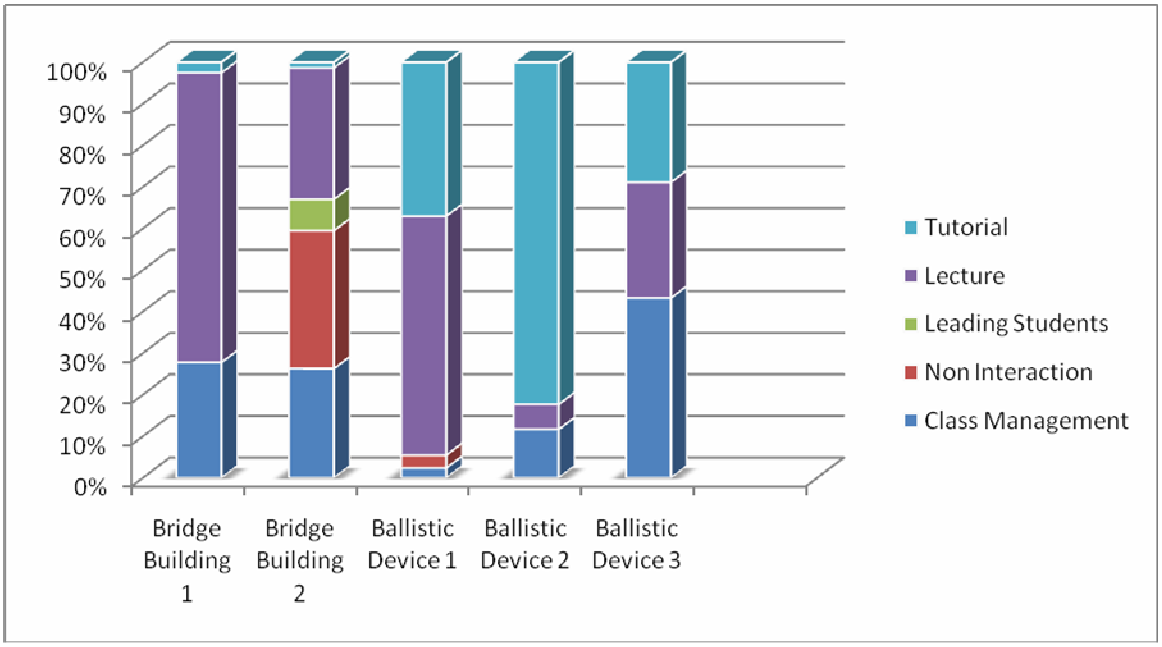

Figure 1: Lesson-wise instruction time breakdown of the five Principles of Engineering classes, where lessons focused either on bridge building or creating a ballistic device.

These data point out an interesting reality of reviewing the enactment of a project-based curriculum, and that is the vast differences between class sessions depending on where in the intended curriculum the students and teacher may be. While in some cases, "non-instructional" tasks (class management and non-interaction) took as much as 40% of the class time (ex. Ballistic Device 3), in other cases, it took as little as 5.5% of the time (ex.

Ballistic Device 1). One interpretation of this is that in some instances where work needs to be checked, collected, and reviewed, fewer instructional activities can take place. Some of this “non instructional” time can be used by the students to work alone or in groups with other students, as discussed in the next section.

Project Work Time

At the core of a project-based curriculum like PLTW are modules wherein students are taught concepts and skills, and then asked to demonstrate the mastery of these concepts and skills through problem solving, often in a hands-on format. Thus, we broke down the in-class time used for project work in order to better understand how this time was spent. In terms of time spent on projects, students spent equally about one third of the time working alone (32.7%), working with other students (34.4%) or working with the teacher (32.9%). In terms of course time overall working on projects took up 54.6% of the combined class period time. This illustrates what we see as a nice variety of forms of interaction between the student, the teacher and other students in the class. Further, using class time for working either alone or with other students on projects allows for good use of the “non-instructional” tasks essential to running a classroom.

Skills and Concepts in the Principles of Engineering™ Curriculum

The next set of tables present a more detailed accounting of each of the concept codes (Table 6) and skill codes (Table 7) that the coders actually applied to the individual video clips. We focused only on the coded skills and concepts. Also, a given video clip of a classroom event can contain multiple skill or concept codes. For this reason, totals can exceed 100%. The first column includes the percentage of the *total number of clips* to which each code was applied (a frequency measure) whereas the second column gives the percentage of the *total amount of class time* to which each code was applied (a durational measure). Discrepancies between these two measures may suggest the relative ubiquity or complexity of a given skill or concept to the subjects of these days’ lessons. For instance, a high percentage in the first column and a low one in the second would suggest that the skill or concept comes up a lot in class but is relatively straightforward to cover, whereas the converse could indicate a skill or concept that doesn’t come up very often but is more difficult to explain or apply. What we observed was a fair balance between the number of clips a given skill or concept appeared in and the amount of class time spent on the given skill or concept. In the detailed breakdown of the concepts covered in the enacted curriculum, we observed a high incidence of the skills that used engineering project work. Measurement, the use of numbers, geometry, design, modeling and structural analysis all occurred at a relatively high rate of incidence (Table 6). In terms of concepts, reasoning, understanding constraints, problem solving and making connections all dominated the class time. This correlates well to what we would expect in a project-based curriculum. Further, it correlates well with the results obtained in earlier analyses of the intended curriculum reported elsewhere[9].

Table 5: Code and time summary for instructional time spent on skills and concepts.

Clip coding	Number of clips (N = 68)		Clip time (T =1:55:47)	
At least one skill code	45		1:29:04	
Skill and no concept codes		4		0:14:50
Skill and one or more concept codes		41		1:14:14
At least one concept code	64		1:40:30	
Concept and no skill codes		23		0:26:17
Concept and one or more skill codes		41		1:14:13

Table 6: Concept Code - Detailed Breakdown.

Concept Group	Concept Code	Frequency of Incidences and Percentage (N =64)		Amount of Class Time and Percentage (T =1:40:30)	
Mathematics					
	Algebra	12	18.8%	0:36:48.83	36.6%
	Geometry	20	31.3%	0:50:20.79	50%
	Measurement	41	64.1%	0:22:37.0	22.5%
	Number	29	45.3%	1:06:12.12	65.9%
Engineering					
	Design Basis	14	21.9%	0:21:51.72	21.8%
	Feedback	1	1.6%	0:03:10.68	3.2%
	Functional Analysis	6	9.4%	0:06:41.28	6.7%
	Modeling	11	17.2%	0:17:29.64	17.4%
	Re-Engineering	1	1.6%	0:0:24.04	0.4%
	Structural Analysis	18	28.1%	0:15:40.55	15.6%
	Loading	3	4.7%	0:02:36.8	2.6%

Table 7: Skill Code- Detailed Breakdown.

Skill Category	Skill Code	Frequency of Incidences and Percentage (N = 45)		Amount of Class Time and Percentage (T = 1:29:04)	
Mathematics					
	Communication	6	13.3%	0:06:57.2	7.8%
	Connections	17	37.8%	0:40:13.92	45.2%
	Problem Solving	18	40%	0:53:56.82	60.6%
	Reasoning	19	40.2%	0:50:43.75	57%
	Representation	14	31%	0:18:14.67	20.5%
Engineering					
	Hypothesis	6	13.3%	0:07:50.26	8.8%
	Project Management	5	11.1%	0:22:02.68	24.8%
	Using Software for Design	2	4.4%	0:1:10.74	1.3%
	Understanding Constraints	8	17.7%	0:34:05.05	38.3%

Comparison of the Frequency of Concept Codes and Skill Codes

An understanding of the underlying principles of engineering and mathematics is essential for genuine learning of the way things work and the “nature of science”[26]. This is an important goal of pre-engineering curricula, such as PLTW ™. Therefore, we reviewed the incidence of concepts and skills separately in order to better visualize what was being taught in the *Principles of Engineering*™ classrooms we visited. Further, we also separated the math from the engineering to see if either was emphasized. Mathematics should be both explained and connected to the engineering In Table 8, we do see that about 33% more time is spent on math than engineering (3 hours, 13 minutes vs. 2 hours, 10 minutes). In relationship to the total class time, this is approximately 75% class time spent using mathematics concepts and skills and approximately 50% of class time using engineering concepts and skills.

Table 8: Comparison of Engineering Codes vs. Math Codes and Concept Codes vs. Skills Codes

Category	Group	Code	Frequency and Percentage of Clip Incidence		Absolute Amount of Time and Percentage of Total Class Time (4:06:58)	
Engineering N_{Total} = 75 clips T_{Total} = 2:10:27.09	Engineering Concepts $N_{concept}$ = 54 clips $T_{concept}$ = 01:05:17.92	Design Basis	14	18.7	0:21:51.72	8.8
		Feedback	1	1.3	0:03:10.68	1.3
		Functional Analysis	6	8.0	0:06:41.28	2.7
		Modeling	11	14.7	0:17:29.64	7.1
		Re-Engineering	1	1.3	0:0:24.04	0.2
		Structural Analysis	18	24.0	0:15:40.55	6.3
		Loading	3	4.0	0:02:36.8	1.1
	Engineering Skills N_{skill} = 21 clips T_{skill} = 01:05:09.17	Hypothesis	6	8.0	0:07:50.26	0.5
		Project Management	5	6.7	0:22:02.68	8.9
		Using Software for Design	2	2.7	0:1:10.74	3.2
		Understanding Constraints	8	10.7	0:34:05.05	13.8
Mathematics N_{Total} = 176 clips T_{Total} = 03:13:04.88	Math Concepts: N_{skill} = 74 clips T_{skill} = 0:17:06.13	Algebra	12	6.8	0:36:48.83	14.9
		Geometry	20	11.4	0:50:20.79	20.4
		Measurement	41	23.3	0:22:37.0	9.2
		Number	29	16.5	1:06:12.12	26.8
	Math Skills: $N_{concept}$ = 102	Communication	6	3.4	0:06:57.2	7.4
		Connections	17	9.7	0:40:13.92	20.5
		Problem Solving	18	10.2	0:53:56.82	21.8

	clips $T_{concept}$ = 02:55:58.74	Reasoning	19	10.8	0:50:43.75	16.3
		Representation	14	8.0	0:18:14.67	2.8

Note: Totals will not add to 100% because events can have multiple skills and concepts codes.

Integration of Mathematics and Engineering

In past work reviewing the intended curriculum (the study of the printed course materials and teacher training manuals), Prevost and colleagues[14] found that *Principles of Engineering* ™ contains more explicitly integrated mathematics and engineering than the first foundations course, *Introduction to Engineering Design* ™ and these current findings of the enacted curriculum in the classroom mirror these findings. In that study, the *Principles of Engineering*™ intended curriculum showed that some standards had greater than 50% explicit integration of math and engineering concepts [14]. *Principles of Engineering* ™ is the second foundation course in the PLTW ™ sequence. Within this course, students learn about various elements essential to engineering: thumbnail and orthographic sketching, perspective drawing, free-body diagramming, the design process, X and Y components of vectors, thermodynamics, fluid and electrical systems, and mechanisms of simple machines. This allows students to work with explicitly integrated mathematics concepts over most of the standards. We found that these activities do a much better job of integration than the *Introduction to Engineering Design* ™ course, which introduces students to engineering and what engineers do through the use of interviews, the internet and in-class work, and was previously reported to have very little explicit integration[9].

The importance of explicit integration cannot be overstated. In order for students--particularly novices entering a highly technical field--to be able to apply the conceptual knowledge learned in their coursework to novel situations, explicit connections must be made for them so that students will have the metacognitive awareness to engage the relevant concepts even when new situations arrive that seem on the surface to be unrelated[27] [28]. All-too-often students can only reliably apply their conceptual knowledge when explicitly prompted to do so, or when they are learning and applying concepts in a very narrow fashion, as when doing end of chapter exercises. Therefore, in order to clarify what these positive and negative examples of explicit integration look like, we have included examples of transcripts from our observed classes showing explicit (Example 1), implicit (where there is an opportunity to present the material explicitly) (Example 2), and no integration (Example 3). To be fair, the instances of no integration represent examples of how materials presented are sometimes particular to mathematics or engineering. In these cases, integration was not possible, and possibly not an instructional goal for the particular lesson.

Example 1: Excerpt illustrating explicit integration of math with engineering

In this example two students are discussing the design of their project, a ballistic device, with their instructor:

1 S: ((At the same time)) Different, different angles.

2 S: A protractor sitting here. With a string with a weight on it. So as you tip it it'll that'll tell you
3 what degree you're tipping it.

4 T: I like that. That's nice.

5 S: So that tells you what degree so we can figure that out.

In this example, the students chose a catapult as their ballistic device, and are explaining how they will measure the angle of trajectory. The mathematics concept central to this discussion is how to measure angles from the vertical. The explicit integration of this concept is how the students hang a weighted string off of the arm of the catapult in order to measure this angle directly (Lines 2-3). These explicit connections indicate that the students understand the mathematics within the context of the engineering, using mathematical terms.

Example 2: Excerpt illustrating implicit integration of math with engineering

In this example, the instructor is getting ready to test the balsa wood bridges that the students constructed using weights in an effort to break the bridge. The students will determine which bridge performed the best by comparing the weight of the bridge to the amount of weight it held. The students must record the weight of the equipment being used as well as their bridge and the variable weights being added in order to perform this calculation.

1 T: The cup, cup is sixty-three grams or two point two ounces. The hook, the hook is four ounces,
2 if you're writing this down, or a hundred and fourteen grams.

3 S: Are we doing this in grams or ounces?

4 T: Your choice.

5 S: Grams.

6 T: You're gonna find grams are gonna be a little more accurate.

7 S: Grams (indecipherable).

8 T: Right, the unit's not important, we don't care if it's ton, pounds, grams, ounces, it's a comparison
9 of one bridge to the others. So I would go grams cuz it's gonna be more accurate.

In this excerpt, the instructor has at least two opportunities to explicitly connect mathematics to the lesson. While they are using math to compute the strength of their bridge, and the instructor does say that they are going to compare one bridge to another (Lines 8-9), this is not an explicit explanation as to why when making ratios the unit is not important for this comparison. Secondly, the instructor mentions that grams are going to be “more accurate” for this comparison than ounces (Lines 6, 8-9), but he does not take the time to explain that grams are smaller units and therefore more resolute, or to explain how one unit of mass can be converted to the other.

Example 3: Excerpt illustrating no integration

In this example, the instructor is reviewing the students' worksheets before they move on to modeling and construction of their ballistic device.

1 T: Kay these are your constraints. Did you look at the Powerpoint with some ideas on it?

2 S: Oh. No I didn't.

3 T: Hm?

4 S: No I didn't.

5 T: Why don't you do that. Go ahead and get some make sure you look and actually you can look at
6 the Powerpoints in any place in the school. (It's on a) shared drive.

In this example, the engineering skill of understanding design constraints (Line 1) is brought up, absent of any discussion about the mathematics or engineering from a conceptual standpoint. You can also get a feel for what it's like to be an instructor in a high school classroom – the student is attempting to complete the assignment, but hasn't done some of the required work that would allow her to do it properly.

Often there is a fine line between no integration and implicitly embedded information. For the purposes of our analyses, we did our best to try to use the clip in context to determine within which category the instance fit best. We used the following criteria: If both math and engineering were mentioned in the clip, but not tied together, this was considered to be implicitly embedded; however, if, as in the last example, it is not clear whether both math and engineering were part of the clip and only one is mentioned, this was coded as having no integration.

As you can see in Table 7, while the amount of explicit integration is light in some categories (such as Algebra, Communication and Representation), overall ideas are explicitly integrated almost 51.8% of the time – indicating over half of the classroom instruction time is devoted to concepts and skills (1 hour 55 minutes over the five class periods). Similarly, there were over twice as many clips that illustrated explicit connections than implicit connections (42.6% vs. 17.6%). While a similar number of clips illustrated no connections as explicit connections (39.7% vs. 42.6%), the amount of class time spent on the explicit connection lesson segments was more than twice that of the no integration segments (51.8% vs. 18.9%, 2.75% more time).

Table 9: Integration of Mathematics and Engineering (Skills and Concepts)

	Explicit Integration Totals : N=29 Time =0:59:45.98 Percent of Clips (Concepts/Skills): 42.6% Percent of Time (Concepts/Skills): 51.8%				Implicit Integration Totals : N=12 Time =0:29:06:00 Percent of Clips (Concepts/Skills): 17.6% Percent of Time (Concepts/Skills): 25.22%				No Integration Totals : N=27 Time =0:21:47.09 Percent of Clips (Concepts/Skills): 39.7% Percent of Time (Concepts/Skills): 18.9%			
	Time	%Time	# of Clips	% of Clips	Time	% Time	# of Clips	% of Clips	Time	% Time	# of Clips	% of Clips
Math Concepts												
Algebra	0:30:48.66	26.7%	7	10.3%	0:01:45.12	1.5%	2	2.9%	0:04:15.06	8.5%	3	4.4%
Geometry	0:44:55.02	38.9%	15	22.1%	0:01:29.64	1.3%	1	1.5%	0:01:36.01	1.4%	1	1.5%
Measurement	0:59:45.00	51.8%	25	36.8%	0:03:31.8	3.1%	5	7.4%	0:08:40.02	7.5%	10	14.7%
Number	0:47:24.42	41.1%	15	22.1%	0:08:57.66	7.8%	6	8.8%	0:09:50.04	8.5%	8	11.8%
Mathematics Skills												
Communcation	0:04:04.86	3.5%	4	5.9%	0:02:46.97	2.4 %	2	2.9%	0:00:00.0	0	0	0
Connections	0:33:01.48	28.6%	8	11.8%	0:001:44.36	1.5 %	2	2.9%	0:02:27.18	1.7%	3	4.4%
Problem Solving	0:43:46.98	38.0%	13	19.1%	0:02: 41.99	2.3 %	2	2.9%	0:06:05.98	5.3%	2	2.9%
Reasoning	0:38:03.72	33.0%	10	14.7%	0:02:42.06	2.3 %	3	4.4%	0:08:35.47	7.4%	5	7.4%
Representation	0:10.25.77	9.0%	7	10.3%	0:04:51.24	4.2 %	3	4.4%	0:02:20.22	1.7%	2	2.9%

Calculation of the percentage of explicit, implicit and no integration for the enacted curriculum was accomplished by dividing the amount of time clips coded in each of these categories by the total amount of time coded as exemplifying any mathematics skill or concept as well as engineering skill or concept. Thus, each level of integration (explicit, implicit or no integration) is divided by T_{Total} = 1:55:47 and N_{Total} = 68, since each clip represents at least one of these categories.

Table 10: Percentage of Explicit Integration of Mathematics Concepts with Engineering Activities in the *Principles of Engineering*™ Intended Curriculum*

	Planning (X_p)		Activities (X_{ac})		Assess-ment (X_{as})		Training (X_t)	
	N_p = 145	Percent Integrat'n (X_p/N_p)	N_{ac}= 32	Percent Integrat'n (X_{ac}/N_{ac})	N_{as}=32	Percent Integrat'n (X_{as}/N_{as})	N_t = 55	Percent Integrat'n (X_t / N_t)
Content Standards								
Number	18	12.4	15	46.9	3	9.4	17	30.9
Algebra	11	7.6	11	34.4	7	21.9	11	20.0
Geometry	15	10.3	9	28.1	1	3.1	17	30.9
Measure-ment	11	7.6	13	40.6	1	3.1	9	16.4
Data and Probability	12	8.3	10	31.3	6	18.8	11	20.0
Process Standards:								
Problem Solving	3	2.1	10	31.3	1	3.1	13	23.6
Reasoning	3	2.1	8	25	1	3.1	12	21.8
Connection	11	7.6	12	37.5	3	9.4	14	25.5
Represent-ation	16	11	14	43.8	6	18.8	21	38.2
Commun-ication	9	6.2	3	9.4	0	0	1	1.8

* For additional information on how these data were generated, see Prevost et al., 2009.

Scoring and calculation of the percentage explicit integration of math concepts for the intended curriculum was accomplished first by identifying the areas of explicit integration in each curricular area (Training, Planning, Activities and Assessments). This was achieved through the comparison of the standard definition with what is presented in the curriculum. The sub-unit was our smallest unit of measurement. In the example given in Table 11 (IED, Unit 6), there are five sub-units including the introduction to the unit. Once items were scored, they were added for each standard within each type of curricular area. These became the numerator X in our calculation of total percent explicit integration. Thus, X is the number of places that were coded as explicitly integrated mathematics and engineering. The total number of items in each curricular area was also tallied. These became the denominator N in our calculation. Thus, the number of opportunities for explicit integration of math and engineering are given by the denominator N for each curriculum and within each curricular area. Percent integration then was simply calculated by dividing X by N (X/N) and multiplying by 100.

Discussion

Our findings from detailed analyses of videotapes of five classroom lessons of the project-based curriculum presented in *Principles of Engineering* ™ allowed us to: (1) better understand how class instructional time is distributed, (2) clarify the nature of how students work in class in order to complete projects that require the use of specialized equipment and knowledge, (3) review what portion of class time is devoted to concepts and skills that are essential for project-based STEM education, and (4) better quantify and understand the amount of class time used to make explicit connections between mathematics concepts and engineering activities. Within the paper are descriptions of advantages and drawbacks to project-based curricula. As we explore new ways to engage and invigorate high school students for future STEM education and technical careers, we look to these curricula as examples of what we might be able to achieve. However, we must be sure that students are given the appropriate opportunities to learn both their core subjects such as math and physics, and to transfer this knowledge beyond its particular presentation in a given class. Therefore, the work of curriculum analysis is essential and important. This analysis, in turn, can be used in future studies to determine how effective the PLTW curriculum is and ways in which it can be improved.

While this investigation provides us with many rich insights, it has some notable limitations that we address here. First, we provide only a snapshot of the enacted curriculum -- five lessons in two different classrooms. The nature of classroom video analysis is quite time intensive, and always selective, thus we cannot possibly make claims about what happens in every classroom. As such methods mature, however, we can look to a broader effort within the community that may provide a richer corpus of the many settings and opportunities in which students encounter pre-college engineering instruction and learning. Second, there are many analytic accounts of the events that occur in these classrooms. Our coding system represents only one such account. However, based on our small sampling and particular theoretical perspective, we can say that an interesting picture emerges when you look into the classroom and see the real circumstances that high school teachers and students encounter. Based on these current findings, we are encouraged by the level of integration in the second tear course in PLTW. We argue that efforts must be made to integrate core subjects such as math and science with the engineering concepts and activities supported by K-12 technology education in these project based curricula more broadly in order that all students may transcend the particulars of any lesson or project and emerge as thoughtful and creative engineers.

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