OREGON APPLIED ACADEMICS PROJECT:

Final Report

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December 2013

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Acknowledgements

The Oregon Applied Academic Project Team wishes to extend its heartfelt thank you to the Oregon math and CTE teachers who participated in this project. Their dedication and determination to embrace change has made a difference.

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MacKenzie Behrle
Rich Berenson
Cliff Brown
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This project was supported through Oregon State leadership funds from the Perkins Act of 2006 and developed in partnership with the National Research Center for Career and Technical Education, University of Louisville.

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Executive Summary

This report contains the findings of the Oregon Applied Academics research and development project which spanned three academic years from 2010 through 2013. The overall purpose of the project was to develop and implement a technical math course that would meet graduation requirements and improve student performance.

The State of Oregon has been actively engaged in the promotion of Career and Technical Education (CTE) curriculum integration over the past decade. The genesis of the Oregon Applied Academics Project began in 2006, with an initial implementation of the Math-in-CTE model with teachers from Lane County Educational Service District. The Math-in-CTE model was developed and tested as an intervention for CTE teachers. As partners in the professional development (PD) sessions, the math teachers learned new, authentic applications of mathematics. However, the math teachers were not provided with a process for integrating their own instruction; the Math-in-CTE model was CTE-driven, addressing the math called for in the CTE context. Notably, the Math-in-CTE model was not developed to address rigor or level of mathematics or order of instruction required to meet state academic standards.

The authenticity, success, and sustainability of the Math-in-CTE model led to new questions about mathematics instruction, congruent with those of the Oregon leaders who proposed the Oregon Applied Academics Project:

- Could a similar or complementary model be developed for mathematics teachers?
- Would it be possible to develop an approach for mathematics teaching, that was both situated in real-world problem and complementary to CTE programs whose teachers were using the Math-in-CTE model?
- Would it be possible to provide CTE students with integrated instruction in their CTE courses *and* concurrently in their mathematics courses?

- What kind of processes would be needed for such an approach?
- What would PD look like?

As the project leaders began to address these questions, they were intentional in drawing upon the tenets of problem-based learning (PBL) to develop a new model for teaching mathematics. The PBL approach situates the learning in a real-world problem and creates an environment for students to learn by exploring the problem and creating solutions for the problem (Beringer 2007; Gülseçen & Kubat, 2006; Hmelo-Silver, 2004). Two hallmark qualities of PBL are: (a) that the student has "not quite enough content knowledge" to solve the problem, and (b) that the problem itself is ill-constructed, meaning that there is not a prescribed or pre-determined path to solution (DeYoung, Flanders, & Peterson, 2008; Zhong, Wang, & Chiew, 2010). Students are compelled to be active participants with ownership in their own learning.

In the first year of the Oregon Applied Mathematics Project, teachers who had previous experience with Math-in-CTE were recruited and trained. Development teams of Math and CTE teachers identified the mathematics embedded in the manufacturing, construction, and engineering curricula. They generated "real-world problems" and "big questions" situated in the CTE content that would require specific mathematics skill to answer. Using a template designed with a PBL approach, they formed the problems and questions into units and identified (a) the overall goal of the unit, (b) the general content of the unit, (c) the CTE concepts addressed, (d) the math concepts addressed, and (e) the Oregon math standards addressed. After units were selected and organized, the teams developed lessons within the units using a seven-element framework adapted from Math-in-CTE model.

The teacher teams developed a technical math course with nine units; the course was piloted in each of the participating districts in Year 2 of the project. Limited pre- and post-testing of math achievement was conducted in three classrooms to ascertain if students were gaining math skills. The preliminary analyses showed a statistically significant treatment effect was detected in those classrooms.

Students and teachers alike provided positive feedback regarding the course, finding it both relevant and challenging. Challenges for teachers included having a lack of knowledge of CTE content, finding gaps in the math content, finding the “tipping point” between math and CTE content, and accommodating students with varying abilities. Benefits included student engagement and empowerment, pedagogy and assessments that ensured students “got it,” benefits of the community of practice, and general excitement of trying something new.

Year 3 heralded the final phase of the project, which expanded the invitation to math teachers from other districts to engage in the professional development. At the conclusion of Year 2, the piloted course units were critiqued, refined, and reordered for implementing and testing in the final phase. The units presented real-world problems within the following CTE contexts: manufacturing, architecture, bridge building, marketing, energy transfer and conservation, electrical power, and construction of roof trusses and staircases. A final capstone project brought all skills together in the construction of a “house” for pets or dolls. The teachers were provided initial professional development in August ahead of the implementation as well as ongoing support throughout the year through additional PD and webinar sessions. Students were pre- and post-tested on measures of math achievement and math attitudes.

Findings revealed that, overall, the math attitudes of students who participated in the technical math course improved more than their peers taking traditional algebra and geometry courses. These results were consistent with the qualitative findings from student interviews conducted in Year 2 and subsequent anecdotal evidence collected in Year 3. In summation, a majority of the students reported that they enjoyed the context-based PBL approach to math and benefitted from the experience of working on the real-world applications.

While overall improvement in math achievement was not greater for technical math students than their counterparts, analysis of ACCUPLACER® (College Board, 2012) scores revealed that students taking the technical math course gained math skills as they participated in the course. Furthermore, results indicated that technical math students with high levels of pretest math achievement improved during the year, while math achievement remained about the same for their counterparts in geometry classrooms. Finally, analysis of the math content within the units of the course met the rigor of Oregon's high school mathematics standards.

The teachers indicated continued satisfaction with the model and observable benefits for their students. All teachers in Year 3 of the project reported they will continue to use the units in the future whether or not the full course is offered in their schools.

Several principles emerged from Oregon Applied Academics Project that echoed those first recognized in the Math-in-CTE research (Stone et al., 2008). These principles pointed to aspects of the model that *made it work*, and findings suggest they provide valuable guidance for future implementations of the model. They include: (a) establishing partnership between math and CTE teachers, (b) fostering a community of practice, (c) maintaining math as the central feature of the problems and questions, (d) adapting the instruction, and (e) recognizing mathematics teachers are not CTE teachers.

Project Overview

In 2007, the Oregon State Board of Education (SBE) released a decision paper that laid out the principles behind the new Oregon Diploma (Oregon SBE, 2007). In addition to proposing increases in credit requirements for core academic content, the SBE expressed the desire to make options available so that the education students receive will be relevant to their college and career aspirations. Specifically, the SBE stated that: "...the math standards may also be met through courses that incorporate the standards such as Integrated Math, Applied Math, Construction Math, and Business Math" (Oregon SBE, 2007). Oregon school districts were allowed to develop alternative approaches to address core academic content; subsequently, questions arose about how best to develop and implement applied mathematics instruction in a way that would maintain the rigor demanded by the standards. The ensuing discussions led to the Oregon Applied Academics Project, a three-year research and development project focused on the development and testing of a technical math course.

Project Purpose

The overall purpose of the Oregon Applied Academic Project was to create a collaborative model for developing a technical math course that would meet graduation requirements and improve student performance. Development of the model was to be based on several criteria, including:

- To be replicable;
- To meet high school math levels, standards, or both;
- To push the rigor in the math;
- To reinforce earlier instruction in new setting, context, or both;
- To be a systematic, intentional approach (not episodic); and
- To involve partnership with career and technical education (CTE).

The course development also was to focus on the mathematics addressed in the Oregon Content Standards (ODE, 2010) as applicable to the Industrial and Engineering Systems Career Learning Area. To that end, the Oregon Department of Education (ODE) contracted with the National Research Center for Career and Technical Education (NRCCTE) to provide the technical assistance and research support required in the development and implementation stages of the project.

Evidence-Based Research

The evidence-based NRCCTE Math-in-CTE curriculum integration model provided the foundation for the development of the Oregon Applied Academics Project. The Math-in-CTE research study was conducted by the NRCCTE from 2004 to 2005. The study involved career and technical education teachers in the content areas of agriculture, automotive technology, business and marketing, health, and information technology; each was paired with a math teacher from his or her local school, district, or community. The CTE-math teacher teams within each of these occupational areas came together for extended professional development – ten days over the course of an academic year – to learn the process and pedagogy of the Math-in-CTE model. They examined CTE curricula to identify embedded mathematical concepts, a process called curriculum mapping. Utilizing a seven-element pedagogic framework, they then developed CTE lessons to enhance the mathematics that existed within the occupational curricula. The CTE teachers scheduled and taught each of the math-enhanced lessons throughout the school year. (NRCCTE Curriculum Integration Workgroup, 2010; Stone, Alfeld, & Pearson, 2008; Stone, Alfeld, Pearson, Lewis, & Jensen, 2006).

The Math-in-CTE research study was conducted with random assignment of CTE teachers to the experimental and control conditions within each occupational area. A total of 136 CTE teachers and more than 3,000 students took part in this study. Fifty-seven teachers were in the experimental group, and 74 were in the control group. Recruitment and random assignment were conducted at the teachers' classroom level rather than at the individual student level. Assignment at the classroom level distributed any unmeasured factors that may have affected the outcome randomly across classrooms and allowed unbiased comparisons of the experimental and control group performance (NRCCTE Curriculum Integration Workgroup, 2010; Stone, Alfeld, & Pearson, 2008; Stone, Alfeld, Pearson, Lewis, & Jensen, 2006).

Students who participated in the math-enhanced CTE classes scored significantly higher than students in the control classes on a traditional measure of math achievement, the Terra Nova standardized exams, and on a commonly used college placement exam, ACCUPLACER. On the TerraNova test, the average experimental class scored at the 71st percentile of the average control-group class. On the ACCUPLACER test, the average experimental class scored at the 67th percentile of the average control-group class. Control and experimental groups scored about equally on the WorkKeys test (NRCCTE Curriculum Integration Workgroup, 2010; Stone, Alfeld, & Pearson, 2008; Stone, Alfeld, Pearson, Lewis, & Jensen, 2006).

Since the conclusion of the study, the Math-in-CTE model has been implemented in 28 states, regions, and large districts. One of the first adopters of the model was Lane County Educational Service District (ESD) in Oregon. The initiative began with small groups of manufacturing and business teachers led by Ms. Kristin Gunson. Encouraged by the success of the initial implementation, Lane County ESD expanded the implementation to new groups of teachers, and, in 2006, the state of Oregon expanded use of the model statewide. As of this report, more than 140 teachers in more than 50 schools have been involved in Math-in-CTE in Oregon, representing an investment of more than $200,000 from ODE.

The Math-in-CTE model was developed and tested as an intervention for CTE teachers. As partners in the professional development (PD) sessions, the math teachers learned new, authentic applications of mathematics. However, they were not provided with a process for integrating their own instruction; the Math-in-CTE model was CTE-driven, addressing the mathematics called for in the CTE context. Notably, the Math-in-CTE model was not developed to address rigor or level of mathematics or the sequence of instruction required to meet state academic standards.

The authenticity, success, and sustainability of the Math-in-CTE model led to new questions about mathematics instruction, congruent with those of the Oregon leaders who proposed this project:

- Could a similar or complementary model be developed for mathematics teachers?
- Would it be possible to develop an approach for mathematics teaching that was both situated in real-world problem and complementary to CTE programs whose teachers were using the Math-in-CTE model?
- Would it be possible to provide CTE students with integrated instruction in their CTE courses *and* concurrently in their mathematics courses?
- What kind of processes would be needed for such an approach?
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Theoretical Frameworks

As the Oregon Applied Academics Project planning team addressed these questions, they moved toward use of a problem-based approach in the development of the technical math course. While some existing context-based mathematics approaches were available, there was overriding concern about the authenticity of the applications. Traditional math problems delivered in a variety of contexts is a helpful step in the direction of relevance and student engagement; however, a fully contextualized approach to teaching mathematics would pose problems as they are encountered in the real world.

Problem-based learning. Problem-based learning (PBL) incorporates knowledge, cooperative skills, problem-solving skills, self-directed learning, and intrinsic motivation. These skills are developed with the intention of the eventual transference to a "real-world" work environment. Whereas traditional approaches build content knowledge, PBL develops the ability of students to seek out, apply, and manipulate the knowledge as a tool for problem solving.

Specifically, the PBL approach situates the learning in a real-world problem and creates an environment for students to learn by exploring the problem and creating solutions for the problem (Beringer 2007; Gülseçen & Kubat, 2006; Hmelo-Silver, 2004). In PBL approaches, it is not uncommon for teachers to pose the problem before introducing the content. In fact, two hallmark qualities of PBL are: (a) that the student has "not quite enough content knowledge" to solve the problem, and (b) that the problem itself is ill-constructed, meaning that there is not a prescribed or pre-determined path to solution (DeYoung, Flanders, & Peterson, 2008; Zhong, Wang, & Chiew, 2010).

In PBL, students are compelled to be active participants with ownership of their own learning process. In addition, they are generally required to work cooperatively with other students with instructors as facilitators (Hmelo-Silver, 2004). Although this may appear at first to represent contradictory requirements, the combination requires students to work cooperatively yet independently to seek out information in a real-world setting (Duch, Groh, & Allen, 2001; Mossuto, 2009). Overall, this kind of knowledge acquisition supports the transfer of the knowledge to other situations.

Situated cognition. Foundational to PBL is the theory of situated cognition. Although it is sometimes difficult to fine-tune the terminology associated with the theory of situated cognition, most agree that it represents a movement away from the individual as an isolated unit into which knowledge may or may not be "plugged" (Moore, 1998). However, much more than simply reversing the process of learning is involved. Situated cognition is a complex interplay between physical and social context, authenticity of experience, and personal construction of knowledge (Darvin, 2006; Hendricks, 2001).

> According to contextual learning theory, learning occurs only when students (learners) process new information or knowledge in such a way that it makes sense to them in their own frames of reference (their own inner worlds of memory, experience, and response). This approach to learning and teaching assumes that the mind naturally seeks meaning in context – that is, in relation to the person's current environment – and that it does so by searching for relationships that make sense and appear useful. (Hull, 1993, p. 41)

The difference between a traditional cognitive approach and situated cognition involves the orientation of transfer of learning. Traditional cognitivism is based on formal schooling as the institutional means for decontextualizing knowledge, with the goal of making it generalizable (Lave, 1990, p. 310) and therefore transferable to situations in the real world. In contrast, the foundation of situative cognitivism is that true learning is context specific (Hendricks, 2001).

A common first step toward contextualized learning is what Hung and Chen (2007) termed *extrapolation.* This approach generally involves the introduction of a concept, then presentation of “real world” problems that can be solved by the application of the concept. The extrapolation approach assumes that knowledge transcends its context. Situated cognition proposes, however, that transfer should be reversed – from specific context(s) to generalization (e.g., Cox, 1997; Greeno, 2006; Hendricks. 2001). In fact, the concept of transfer can be difficult to analyze because it is treated as both a cause and an effect (Langer, 2009).

Langer (2009) refers to two separate categories of transfer of learning: lateral and vertical. These categories parallel the horizontal and vertical concepts of curriculum integration, which can be defined by perspectives of curriculum and ability level, respectively (NRCCTE Curriculum Integration Workgroup, 2010). Lateral transfer of learning can occur between related conceptual topics; vertical transfer can help the student apply prior learning to new or more advanced topics (Kerr, 2000). Regardless of the method of instruction or the physical, curricular, or social context, transfer of learning is a vital process of instruction.

Transfer is not an automatic process: students must be taught how to transfer knowledge (Hendricks, 2001). Brown, Collins, and Duguid (1989) alluded to this transfer when they compared knowledge to a set of tools that are adaptable in the hands of a worker to do more than one thing. They also termed learning activities that "matter" to be authentic. Likelihood of transfer can be increased by creating as authentic an environment (including the ingredients) and activity as possible (Brown et al., 1989; Paige & Daley, 2009). However, a prevailing problem with transfer of learning is the difficulty in measuring it appropriately; retrieval and demonstration of transfer can vary from student to student, sometimes varying considerably from the assumption of the curriculum developers (Langer, 2009).

Context, authenticity, and transfer are hallmarks of the theory of situated cognition. Another defining property is social interaction. "The idea that learning results from complex social interaction is central to the theory of situated cognition" (Hendricks, 2001). However, as mentioned previously, the meaning and implication of words can vary, depending on which theorist is doing the talking. Social interaction, communal practice, and group negotiation of knowledge are all activities that involve face-to-face engagement; however, a less concrete assumption is that all individual actions are viewed as aspects of an encompassing system of social practice (Cobb & Bowers, 1999). In this way, the social system is considered part of the issue of context, even when students are "peripheral participants" (Lave & Wegner, 1991). The social aspect is vital to the theory of situated cognition, and some claim that problem-solving strategies can only be gained in authentic activities through sustained participation within a community (Brown et al., 1989; Hendricks, 2001; Lave, 1990).

Development Phases of the Model

The Oregon Applied Academics Project was designed as a three-year research and development (R&D) project with three distinct phases as shown in Figure 1. Each phase of the iterative process was utilized to (a) develop key aspects of the model, (b) collect data to inform improvements, and (c) complete the refinements essential to the next phase.

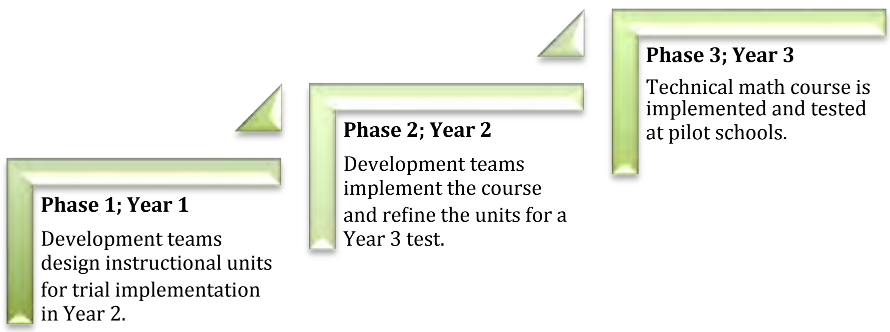


Figure 1. Three Phases of the Oregon Applied Academics Research and Development Project

Phase 1; Year 1: Developing the Units

A first step in launching the overall project involved the recruitment and selection of high school math teachers to participate in the first two years of the development process. Prior to the recruitment period in Spring 2010, school and district administrators were invited to a meeting to learn more about the project. Oregon and NRCCTE project leaders introduced the purpose of the project, made explicit the links to Oregon initiatives and standards, and established the research foundations undergirding the approach. Project leaders introduced the administrators to requirements for participation, which centered on a two-year commitment with specified funding support from the state. The teachers' participation was predicated on these key criteria:

- Previous or concurrent involvement in Math-in-CTE,

- Involvement of a CTE teacher partner,
- Commitment in Year 1 to participate in professional development sessions and course development,
- Commitment in Year 2 to participate in professional development and teach the course, and
- Participation in data collection both years.

Teacher professional development cycle. The project officially launched in August 2010 when the math and CTE teachers came together and formed development teams for the first professional development (PD) sessions at Lane County ESD in Eugene, Oregon. All subsequent PD sessions have been hosted at Lane County ESD. In Phase 1, the math-CTE teacher development teams met for a total of 9.5 days:

August 19-20, 2010: 2 days

October 28-30, 2010: 2.5 days

March 10-12, 2011: 2.5 days

July 25-27, 2011: 2.5 days

Identifying the mathematics in industrial and engineering systems. At these first PD sessions, participating teachers were introduced to the purpose, goals, and expectations for the first two years of development. The project leaders guided the development teams in a mapping exercise to identify the mathematics embedded in manufacturing, construction, and engineering content. The teams generated “real-world problems” and “big questions” situated in the CTE content that would require specific math skills to answer. Using a template designed with a problem-based learning (PBL) approach (see Appendix A), they formed the problems and questions into units and identified (a) the overall goal of the unit, (b) the general content of the unit, (c) the CTE concepts addressed, (d) the math concepts addressed, and (e) the math standards addressed.

While the process of mapping began with the identification of manufacturing, construction, and engineering problems and questions, an essential criteria was that CTE content not dominate the decisions about the teaching of mathematics. Therefore, particular attention was given to finding the kind and level of mathematics that should be a part of a technical math course and ensuring the course would meet state requirements for graduation. A process of negotiating this balance between authentic context and math content occurred between the development teams as they developed each unit and among the teams in the larger community of practice. This negotiation became a central feature of the development process; the project leaders routinely encouraged such discussions as the units were reviewed and revised throughout both years.

Developing the units. By the conclusion of the August 2010 sessions, the math-CTE teacher development teams had identified nine possible units for development. Each team left with one unit to develop fully before the next PD session. When the teams reconvened in October 2010, the project leaders facilitated a review and critique of each of the units; teacher teams provided each other with written feedback to guide the next iteration of edits. Care was taken to question the usefulness of the units identified in the first sessions and to determine if any units should be re-conceptualized or possibly eliminated. The teachers also reached an agreement on the math concepts to be addressed in each unit and the sequence for their instruction, an essential step in scaffolding the math instruction both within and across the units.

Developing lessons within the units. Once the units were selected and organized, the teams began to work on the development of the lessons within the units. For this purpose, they used a seven-element framework that project leaders had adapted from the tested Math-in-CTE model (see Appendix B). The lesson framework included elements to ensure that each of the lessons (a) remained situated in the real-world problem, (b) addressed the transfer of learning from the context to the abstracted mathematics, and (c) provided opportunities for authentic assessment.

The teams worked on their own to create the lessons within their units until they reconvened again in March 2011. This process was aided by the development of a web-based repository for the lesson development. As new versions of the units were prepared between the PD sessions, the teachers uploaded them for advanced review. The purpose of the March sessions was to engage in a deep and systematic review of the units with the intent of implementation in the following academic year. During these sessions, the project leaders engaged teams in a modified *critical friends* process (Bambino, 2002) (see Appendix C) through which each team presented their unit to another team and received in-depth feedback; three rotations of this process ensured a depth and breadth of feedback. At this point in Phase 1, the development teams committed to complete revisions of the lessons and units and to a final upload to the web-based repository by June 2011 for implementation in the 2011-2012 academic year.

Bridging to the Phase 2; Year 2 implementation. The Oregon Applied Academics Project was proposed as a research and development (R&D) project with the assumption that creating a new problem-based approach to teaching mathematics would require flexibility and responsiveness. As project leaders reviewed the units submitted in June 2011, they determined that more revisions would be needed for successful implementation of the course in the following academic year and that in-person professional development would be the best possible venue for this purpose. Therefore, development teams were reconvened in July 2011 to engage in another round of refinements in order to make a seamless transition into the launch of the unit implementations in Fall 2012.

Throughout all phases, project leaders did not assume the teachers' knowledge of or experience with a PBL approach. Therefore, at each PD, they reinforced the approach with supplementary information, journal articles, and PowerPoint presentations. These supports and resources addressed topics such as contextualized teaching practices, authentic teaching and learning, transfer of learning, authentic assessment, and even copyright regulations.

Phase 2; Year 2: Implementing the Units

Phase 2; Year 2 focused on a pilot implementation of the technical math course at each of the participating schools. The recommended course offering was one credit of Technical Math, under NCES Code 02153, with this description:

> *This class will help you understand the mathematics used in careers, including engineering, construction, manufacturing, and marketing. You will explore the geometry of bridges, how algebra can help light a home, and how statistics can make your next great idea profitable. Each of the nine topics includes the math you might find in other high school classes as well as a chance to design, create, and solve problems using that math. This class can be applied to the math credits required for an Oregon High School Diploma.*

Teacher professional development cycle. The teacher PD in Year 2 shifted focus from development and revisions of the units to supporting the implementation of the course. Project leaders were reluctant to pull teachers out of the classroom for excessive amounts of time; therefore, the in-person PD sessions were reduced to four-and-a-half days and augmented with monthly webinar sessions. As the development teams and their respective schools committed for two years only, a final debriefing day was scheduled for June 2012.

Professional development:

August 15-17, 2011: 2.5 days

December 9-10, 2011: 2 days

Webinars (up to 2 hours each):

October 1, 2011

October 22, 2011

November 19, 2011

January 21, 2012

February 25, 2012

April 7, 2012

May 12, 2012

Final debriefing session for Years 1 and 2:

June 21, 2012: 1 day

Implementing the course. The August 2011 PD session offered a seamless transition into the Year 2 implementation of the technical math course. The designation between the July and August PD sessions was relatively artificial in terms of the teacher experience. Given that the revisions were completed in July, PD in Year 2 was almost exclusively devoted to unit presentations by the developing teams. Each presentation provided a thorough walk-through of the lessons within the unit with the expressed intent of helping the group prepare for launching the new course. The development teams highlighted key aspects of the instructional methods, demonstrated the skills essential for the lab activities, and provided details about the supplies and resources required to complete the unit. The first five units were presented in August; the remaining four were presented in December. At the conclusion of each PD session, the math teachers completed a teaching calendar to guide completion of the units and ensure the timely delivery of content.

Collecting data. Data collection was initiated in Phase 2 for the purpose of informing refinements of the model. The following data were collected for preliminary analysis:

- Student measures:
    - Pre- and post-testing of mathematics ability in selected classrooms (ACCUPLACER®) (College Board, 2012)
- Teacher measures:
    - Pre- and post-PD teacher surveys
    - Online pre-unit reports from CTE partners
    - Lesson-by-lesson reports from the math teachers
    - Post-Year 2 focus groups

The project leaders worked together to ensure the fidelity of the implementation. Of particular importance was the process of monitoring the teaching reports and making site calls and visits to ensure that the implementation was indeed underway. The webinars also provided another valuable source of data for monitoring the teaching progress.

Refining the units for implementation in Phase 3; Year 3. At the conclusion of Phase 2, the development teams involved in the initial development of the units were invited to stay on to refine the units for testing the model in Year 3. Two additional days in Summer 2012 were dedicated to this task. Data gathered from the surveys and debriefings and notes from the teachers' experiences with the course were used to embark on a systematic examination of each unit, guide the rewrites of lessons, and determine the order of instruction in preparation for the August 2012 launch.

Phase 3; Year 3: Testing the Model

Phase 3 was the last and final year of the research and development (R&D) project. Given that the technical math course had been developed and refined in Phases 1 and 2, Phase 3 involved full implementation of the yearlong technical math course to test its impact. The focus was two-fold: (a) to engage math teachers from other schools to participate in the professional development, and (b) to collect and analyze data from the participating schools.

Year 3 teacher professional development cycle. The recruitment phase for Year 3 began in Spring 2012 as state personnel contacted administrators and teachers throughout the state to solicit their participation in the project. Districts were invited to apply for grants from the state, which were designated to support their participation in the project.

Following the recruitment phase, the Phase 3 teacher professional development (PD) sessions launched in August 2012. Sessions again were conducted at Lane County ESD in Eugene, Oregon. August sessions ensured that the teachers would have enough time in advance of the school year to (a) become familiar with the technical math course, (b) learn and practice the problem-based approach, (c) make the necessary adjustments to their course syllabi and classroom structure, and (d) prepare for the student pre-testing. Supplies to support the various CTE-based activities were also distributed at the PD sessions; as in the previous phases, the teachers were not required to order or plan for these activities on their own.

Previous iterations in the earlier phases of the project revealed the need for ongoing support throughout the school year. Therefore, the teachers returned for follow-up PD sessions in Fall 2012 and Winter 2013 and also participated in the webinars offered monthly between the in-person sessions.

Professional development:

August 8-10, 2012: 3 days

October 25-26, 2012: 2 days

February 1-2, 2013: 2 days

Webinars (approximately 1 hour each):

September 24, 2012

November 17, 2012

December 15, 2012

January 12, 2013

March 2, 2013

April 6, 2013

April 27, 2013

Final Debriefing Day:

June 28, 2013

Planning the professional development sessions for implementation and testing of the model in Phase 3 posed some unique challenges. The participants in this phase were a blend of returning development teams with 2 years of experience continuing into the final phase and new math and CTE teachers joining the project. The solution to this challenge was to take full advantage of the resident capacity of the experienced teachers to provide leadership and support to those teachers new to the experience. This was accomplished in two ways: (a) by intentionally pairing new teams with returning teams who could lend their wisdom and support, and (b) by encouraging returning teachers to lead certain aspects of the PD sessions.

Implementation of the technical math course. While the math teachers' development remained at the fore of the project, increased emphasis was placed on ensuring the systematic and accurate delivery of the units for the purpose of student testing; thus, the implementation was closely monitored throughout the year through the online teaching reports, during webinar discussions, and through reflective activities during the PD sessions. The tenets of problem-based learning were introduced in August 2012 and continuously reinforced in the sessions throughout the year with presentations and supporting materials. Introducing instructional strategies such as use of cooperative learning groups and lab management was also an essential aspect. A majority of time during the PD sessions was placed on providing walk-throughs of each unit with interactive demonstrations of key aspects of the learning activities to ensure consistency and accuracy in the application of mathematics in the context of CTE (see Appendix E).

During the project revision meetings in Summer 2012, participating teachers from the earlier development phases recommended that all nine original units of instruction remain in the technical math course. Project leaders questioned this recommendation because none had completed all nine units in the Year 2 pilot implementation. However, consensus among the math teachers was that completion of all units was possible within a year and that all were worthy of instruction with regard to the math content. They recommended a re-reorder in the sequence of units for two main reasons: (a) to better accommodate the conceptualization and/or scaffolding of math content, and (b) to provide their students with some relief from consecutive construction projects. They also requested some latitude to adjust the order of instruction of the units, as well as lessons within the units, to accommodate students' needs; these adjustments were reported at the PD sessions and in the monthly teaching reports. As an outcome of teacher engagement in the development process, the recommended order of units was adjusted for final implementation of the technical math course and testing in Year 3.

Project Outcomes

The Oregon Applied Academics Project spanned three academic years from Summer 2010 through Summer 2013. This section reports the cumulative project outcomes from data collected throughout the project.

Participating Teachers and Districts

The teachers who participated in the first two years of the project were all volunteers who were supported by their schools or districts through application to the State of Oregon and who met the selection criteria outlined in an earlier section of this report, *Development Phases of the Model*. Thus, the sample was purposive and consistent with what is expected in a development project of this kind.

Nine teacher development teams of math teachers and CTE teacher partners began the project in Summer 2010. These development teams, representing a variety schools and districts from across the state (see Appendix D), committed to participate in the first two phases of the project. By Spring 2011, project leaders learned that four teachers would not be able to continue in the Year 2 implementation primarily due to teaching reassignments and budget cuts. As a result, the number of participating math teachers and districts dropped to seven from the original nine. In Year 2, each of the seven participating districts implemented at least one section of the class; two districts implemented two sections, and one district implemented three sections.

With the development phases completed, Year 3 signaled a shift in focus to implementation of the technical math course and testing of students' math achievement. Teachers who were involved in the development of the course were invited to continue participation. Teachers from other districts, who had not previously participated in the project, were also invited to join the initiative. Of the original teams, four math teachers returned, three with CTE partners. Two new math teachers joined, one with a CTE partner; one CTE partner returned without a math teacher to provide ongoing support for the two math teachers who were without CTE teacher partners.

The Technical Math Course

The iterative process used in the first two phases of the project resulted in the development of a technical math course with nine units of problem-based instruction. As the primary intent of the course was to serve CTE students taking courses in the Industrial and Engineering Systems career area, each of the units was formed around identified real-world problems or big questions within that scope, primarily in manufacturing, construction, and engineering, thus complementing the CTE program content. It is important to note that while the units were named for their CTE foci, the embedded mathematics dictated the order of instruction.

Following the pilot implementation in Year 2, the math teachers who participated in the refinement meetings retained all nine units but changed the order of instruction to better sequence the math concepts. More specifically, they proposed to lead students through increasingly difficult math concepts, balancing the difficulty of the applications as they moved through the year to reach the capstone project. They also sought to provide some variation in the learning activities at opportune times of the school year. Below is a summary list of the problem-based units in the recommended order of instruction[1]:

- Manufacturing:

  How do manufacturers determine the precision of measurement needed for the production of interchangeable parts? How are three-dimensional items produced from two-dimensional patterns?

- Architecture:

  How do architects design and locate homes to best work with the natural and built environment?

- Bridge:

  How do we build a bridge or structure with triangles? What is the relevance of utilizing and knowing geometry related to triangles, angle relationships, and linear relationships in construction and architecture?

- Marketing:

  How do we use statistics through the lenses of marketing?

  Statistics? What does that mean?

- Energy Transfer and Conservation:

  What type of insulation is most efficient and most cost effective for building a structure?

- Electrical:

  What are the electrical power needs for your ____?

- Roof Raising:

  How do we build a scale barn with truss construction?

- Staircase:

  How do we use math to build a set of stairs within a specified area with distinct specifications and parameters?

- Animal House (Capstone Project):

  How do I build a home for my _____?

The totality of mathematics addressed in the units represented a combination of algebra, geometry, and statistics. While situated in the CTE content for the purpose of instruction, an essential criterion was the course remains clearly focused on the math content. To that end, the development teams identified and labeled the specific mathematics standards met by each lesson within the units. The curriculum map (see Appendix E) provides a full analysis of the math concepts addressed in each unit. The math teachers identified the level of mathematics in the course as bridging Algebra I and II, and recommended Algebra I as a pre-requisite for future students enrolling in the course.

Data Collection

The project team collected data throughout Phases 1 and 2 of the project as a function of the iterative process in developing and refining the technical math course as a whole. In addition, the state utilized ACCUPLACER® exams in Phase 2 to conduct limited preliminary pre- and post-tests of math achievement of students in the pilot classrooms. The primary objective of testing was to ensure that a positive treatment trend was observed within ACCUPLACER® performance of students enrolled during the development phase. Given the scope of the initial implementation and the restricted student numbers, treatment effects were not anticipated. However, among the three classrooms included within the analysis, a statistically significant treatment effect was detected (see Appendix F).

Data collection continued in Year 3, which added the existing measures of the pre- and post-testing of students in the technical math classrooms and comparison classrooms on measures of math achievement and math attitudes. The following data sets were collected for final analysis of the project:

- Student measures:
  - Pre- and post-testing of mathematics ability in selected classrooms (ACCUPLACER®) (College Board, 2012)
  - Pre- and post-testing of math attitudes (ATMI) (Tapia & Marsh, 2004)
  - Demographic student surveys
  - Student interviews (Year 2 only)
  - Artifacts of student activities and accomplishments

- Teacher measures:
    - Pre- and post-PD teacher surveys
    - Online unit reports from the math teachers
    - Online pre-unit reports from CTE partners
    - End-of-project focus groups

The project leaders monitored the fidelity of the implementation by tracking the teaching reports and making site calls and visits to ensure that the implementation was indeed underway. The webinars between PD sessions also continued to provide another valuable source of data for monitoring the teaching progress.

Student Testing Procedures

While development of a problem-based technical math course and the accompanying teacher professional development remained a focus of the project, Year 3 brought the testing of students to quantify the effectiveness of the model. Students in the classrooms of participating math teachers were administered demographic surveys, standardized tests of mathematics, and math attitudes inventories.

The ACCUPLACER® Elementary Algebra test (College Board, 2012) was selected by the state project leader for testing the mathematics achievement of the students in classrooms of the participating teachers. The ACCUPLACER® is a widely acknowledged and reliable college placement exam, appropriate for the grade level of students taking the technical math course. An online version of the exam was also readily available for use by the state, making it both doable and affordable for the project.

The Attitudes Towards Math Inventory (ATMI) (Tapia & Marsh, 2004) was selected to ascertain if using a problem-based approach to mathematics impacted students' attitudes toward mathematics[1]. The ATMI is a widely recognized instrument with established validity and reliability. The 40-question instrument utilizes a 5-point Likert scale on multiple factors to ascertain high school and college students' attitudes toward mathematics.

The classroom teachers administered pre-tests and surveys within the first two weeks of the technical math course; post-tests were administered within the last two weeks of the course. Each of the participating math teachers also identified and tested a comparison classroom. Since the technical math course was unique, the teachers selected comparison classrooms based on their best judgment of the students' mathematics abilities upon entry into the courses. As a result of this process, students from a combination of Algebra I and Geometry classrooms were tested. Descriptive statistics for student level variables are displayed in Table 1.

Table 1
Descriptive Statistics

Variable Type	Variable Name	n	%	
Group	Geometry	84	27.0	
	Algebra	82	26.4	
	Technical Math	145	46.6	
Gender	Male	178	57.2	
	Female	133	42.8	
Ethnicity	White	275	88.0	
	Hispanic	12	4.0	
	Amer. Indian	12	4.0	
	Asian	5	2.0	
	African American	6	2.0	
	Hawaiian	1	0.003	
		Coding	μ	*SD*
Other	Age		15.80	.88
	Grade Level		11.99	4.25
	Avg Grade	1 = F to 9 = A	6.58 (~BC)	1.52
	Future School Plans	0 = less than high school to 6 = PhD	3.64 (~BA)	1.77
	Work Hours		.67	2.34
	# Math Courses		2.80	1.43
	# CTE Courses		1.52	1.7

[1] Developers of the ATMI granted permission for use of the instrument in this project.

Quantitative Analysis

Missing data. We conducted a missing data analysis because the data were longitudinal and attrition was a concern. Three-hundred eleven (311) cases across 89 variables were initially available for analysis. We examined the variables carefully and found that the prevalence of missing information ranged from 22.2% to 55.9%. To address this issue, we used multiple imputations, a state-of-the-art method for handling missing data that incorporates imputation uncertainty into the analysis model, producing more conservative standard errors (Enders, 2010).

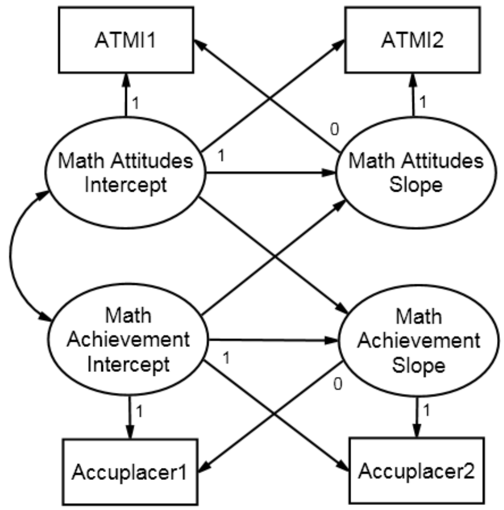
Exploratory Factor Analysis (EFA). We used Maximum Likelihood to explore the dimensionality of the 40 pretest ATMI items and found that a single factor subsumed 51% of their variance. Loadings ranged from .46 to .85, suggesting that the pretest items provided reasonably reliable and valid measurement of math attitudes. Using the same method, we examined the dimensionality of the 40 posttest ATMI items and found that a single factor subsumed 49% of their variance. Loadings ranged from .45 to .88, suggesting that the posttest items also provided reliable and valid measurement of their construct. We saved factor scores for the two math attitudes factors using the regression method and specified these as observed variables in our hypothesized model. All analyses were carried out in SPSS 21.

Latent Growth Modeling (LGM). In this study, we employed a restricted form of latent growth curve modeling, termed latent growth modeling (LGM), because we had math attitudes and achievement data for only two time points. Despite this, LGM provided valuable information regarding the effects of our intervention on change in math achievement and attitudes and also information bearing on whether assignment to the technical math classrooms was associated with any student characteristics. While traditional approaches generally allow researchers to test for significant change over time, these approaches do not allow for conclusions about variability in rates of change among participants. LGM allowed us to test for significant rates of change, variability in change rates, and model predictors of both types of variation.

In this study, we used MPlus 6.11 to test the hypothesized models, raw data as input, and Maximum Likelihood as the estimator. We used the complex function to account for the clustering (i.e., nesting) of students in classrooms and used dummy variables to account for the nesting of classrooms within teachers. All tests of significance were conducted at $p < .05$. To evaluate model fit, this study used a variety of commonly used fit indices and their rules of thumb (e.g., Tucker-Lewis index, comparative fit index, and root means square error of approximation; see Kline, 2010).

Hypothesized Models.

Baseline model. Our first hypothesized LGM was a baseline model that contained observed variables corresponding to ACCUPLACER and ATMI scores at Time 1 and 2. The model also included latent variables corresponding to intercepts for math achievement and attitudes, along with slopes for math achievement and attitudes. We tested the baseline model to examine whether the latent intercepts and slopes were significantly different from zero and characterized by statistically significant variation across our participants. If significant variation was observed, we planned to test a second model that included covariates in an attempt to explain the variance. Figure 2 displays the hypothesized baseline LGM.



Note. Covariates are omitted for conceptual clarity.

Figure 2. Hypothesized Baseline LGM

Full LGM 1. Our second hypothesized model included all the baseline model variables plus a dummy variable representing whether participants were in the technical math classrooms, along with covariates including classroom mean math achievement, teacher code (dummy variables compare teachers 2-5 against teacher 1), sex (0 = male, 1 = female), dummy variables representing ethnicities (each group compared to Caucasians), grade level, age, average grade, future school plans, work hours, number of math courses taken, and number of CTE courses taken. All intervention group variables and covariates were exogenous to the change rate variables specified at baseline. We tested this second model to explain any observed variance in the intercepts and change rates among our participants.

Full LGM 2. Our third hypothesized model included all the second model's variables plus dummy variables representing whether participants were in algebra classrooms or geometry classrooms rather than technical math classrooms. We tested this second model to compare technical math classroom math achievement and attitudes intercepts and slopes to each of the types of comparison classrooms.

Interactions. Prior research examining the effects of CTE-type interventions indicates that such interventions may not have homogeneous effects across levels of pretest achievement (Pearson, Young, & Richardson, in press). Thus, in this study, we planned to add group (i.e., algebra or geometry rather than intervention classrooms) by pretest achievement interactions to our second full LGM. We also planned to include group by sex and group by number of CTE credits interactions to test whether the treatment effect depended on these variables. In particular, one scenario could be that students with more CTE courses were more familiar with the content of the intervention and better able to benefit from it.

Results.

Baseline LGM. We tested the hypothesized baseline LGM for fit to the data as seen in Figure 2. This hypothesized baseline model was just-identified, producing no relative fit information, but allowed us to test for significant variance in intercepts and change rates. We observed that the means for the math achievement intercept and slope means were statistically significantly different from zero, while the math attitudes intercept and slope means were not. This latter finding was expected because factor scores were centered at zero. We observed average baseline math achievement at 41.16, and that, on average, achievement grew by 5.48 points. In addition, significant variance in all intercepts and slopes was observed, suggesting that using group and covariates to try to explain this variation was useful. Finally, we observed a moderate significant negative effect between the math achievement intercept and slope ($\beta = -.40$) and a small negative effect between the math achievement intercept and math attitudes slope ($\beta = -.13$), suggesting that higher achievers at pretest improved less in terms of achievement and attitudes than lower achievers. Similar, the math attitudes of those with better pretest attitudes improved less ($\beta = -.40$) than those with poorer pretest attitudes. The achievement and attitudes slopes (i.e., rates of change) were not significantly correlated, while the intercepts were significantly and moderately negatively correlated (*r* = -.35). The latter indicated that, at baseline, those with better math achievement had poorer math attitudes.

Full LGM 1. We tested the hypothesized full LGM for fit to the data. This hypothesized model was over-identified with 34 degrees of freedom. We observed that the fit indices suggested that this model fit the data well. The model produced an average RMSEA value (i.e., across the imputed sets) of .05, CFI value of .99, and TLI value of .97. In addition to interpreting fit indices, we interpreted the substance of the model's statistically significant parameter estimates (see Appendices I and J).

We observed that the math achievement and attitudes intercepts had significant large (β = -.63) and small (β = -.24) negative effects on the math achievement slope, respectively. Similarly, the math attitudes intercept had a moderate negative effect (β = -.45) on the math attitudes slope. The achievement and attitudes slopes were not significantly correlated, while the intercepts were significantly and moderately negatively correlated (*r* = -.31), indicating that at baseline, those with better math achievement had poorer math attitudes. In addition, students in the technical math classrooms began with poorer math attitudes than students in comparison classrooms (*r* = -.20). Holding all covariates constant, being in the technical math classrooms was associated with a small positive effect (β = .10) on improvement in math attitudes as seen in Figure 3, while growth in math achievement was not significantly different between the technical math and comparison students.

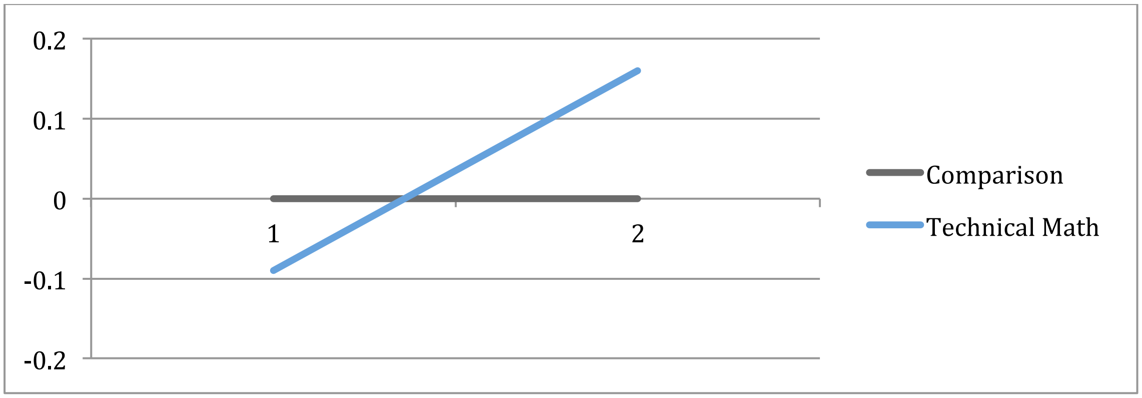
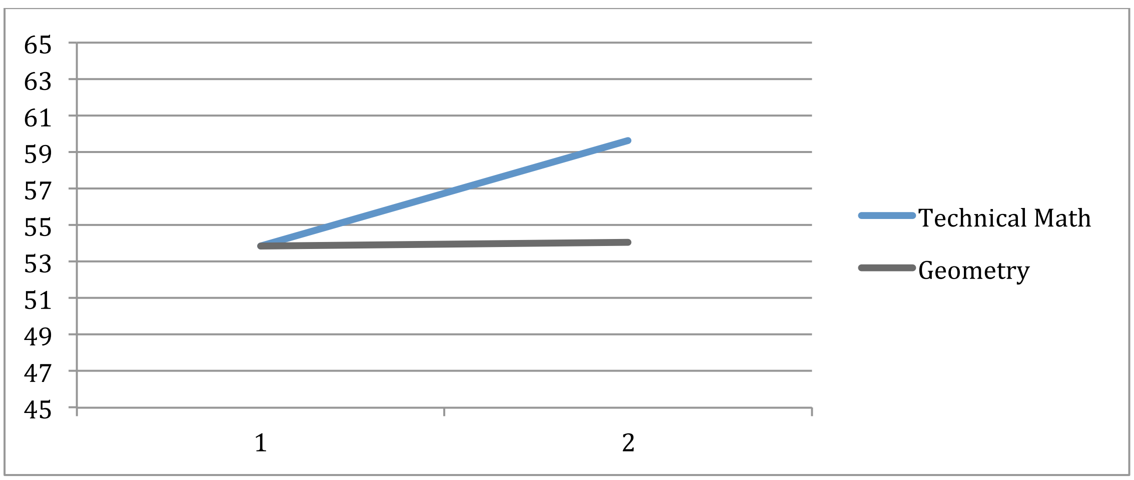


Figure 3. Math Attitudes Change Trajectories for Technical Math and Comparison Classrooms

Full LGM 2. We tested the hypothesized full LGM for fit to the data. This hypothesized model was over-identified with 51 degrees of freedom. We observed that the fit indices suggested that this model fit the data well. The model produced an average RMSEA value (i.e., across the imputed sets) of .06, CFI value of .97, and TLI value of .94. In addition to interpreting fit indices, we interpreted the substance of the model's statistically significant parameter estimates (see Appendices I and J).

We observed that the math achievement and attitudes intercepts had significant large (β = -.63) and small (β = -.24) negative effects on the math achievement slope, respectively. Similarly, the math attitudes intercept had a moderate negative effect (β = -.43) on the math attitudes slope. The achievement and attitudes slopes were not significantly correlated, while the intercepts were significantly and moderately negatively correlated (r = -.32; see Appendix K). This indicated that, at baseline, those with better math achievement had poorer math attitudes. Holding all covariates constant, students in algebra classrooms experienced slightly greater improvement (β = .07) in math achievement than students in technical math classrooms, while growth in achievement for geometry students was not significantly different. Controlling for all covariates, students in algebra classrooms experienced less growth in math attitudes (β = -.14) than students in technical math classrooms. Attitude growth for students in intervention and geometry classrooms was not significantly different.

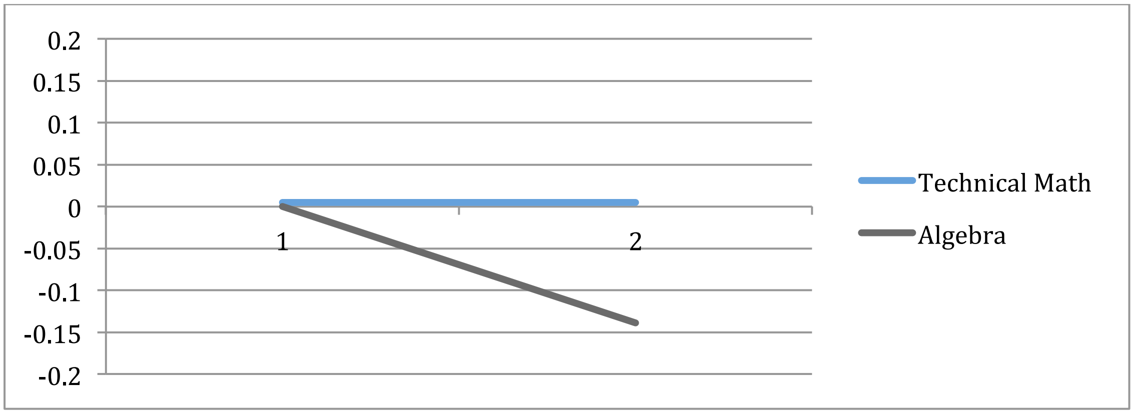
Interactions. We included group by pretest, sex, and number of CTE credits interactions in the model to examine whether the effects of being in technical math classrooms (or not) depended on these variables. See Appendices I and J, far right columns, for significant interaction effects. We found that, holding all other predictors constant, the group by sex and number of CTE credits interactions were not significant predictors of the math attitudes and achievement slopes. The geometry by pretest math achievement interaction had a significant negative effect on the math achievement slope as seen in Figure 4, suggesting that students in geometry classrooms with higher pretest math achievement scores improved less in terms of math achievement than those in technical math classrooms.



Note: Chart depicts change trajectories for students falling one standard deviation above average on pretest math achievement.

Figure 4. Math Achievement Change Trajectories for Higher Achieving Technical Math and Geometry Students

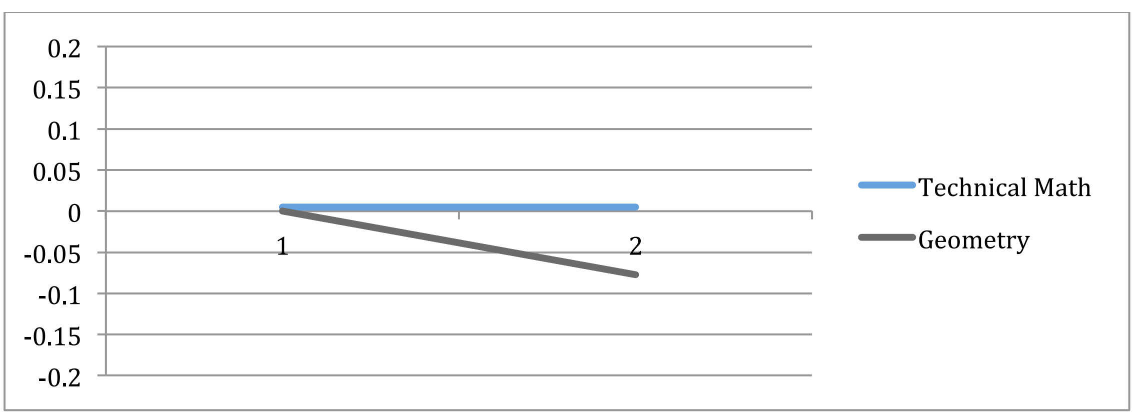
In addition, the algebra by pretest math achievement interaction had a significant negative effect on the math attitudes slope, suggesting that students in algebra classrooms with high pretest math achievement scores worsened in terms of math attitudes, while higher achievers in technical math classrooms did not, as seen in Figure 5.



Note: Chart depicts change trajectories for students falling one standard deviation above average on pretest math achievement.

Figure 5. Math Attitudes Change Trajectories for Higher Achieving Technical Math and Algebra Students

Similarly, the geometry by pretest math achievement interaction had a significant negative effect on the math attitudes slope, suggesting that students in geometry classrooms with high pretest math achievement scores worsened in terms of math attitudes, while higher achievers in technical math classrooms did not as shown in Figure 6.



Note: Chart depicts change trajectories for students falling one standard deviation above average on pretest math achievement.

Figure 6. Math Attitudes Change Trajectories for Higher Achieving Technical Math and Geometry Students

The simple effects observed for being in algebra and geometry classrooms were no longer significant once the algebra and geometry by pretest math achievement interactions were included in the model. These findings suggest that, holding all other predictors constant, the effect of being in technical math classrooms depended on pretest math achievement level, with technical math classrooms appearing to improve math achievement for those students with high pretest scores to a greater extent than geometry classrooms, and also appearing to protect against the decreases in math attitudes observed for high achievers in algebra and geometry classrooms.

Discussion. The quantitative portion of this study suggested that, overall, students in technical math classrooms started out with poorer math attitudes at pretest, but their math attitudes improved more than students in comparison algebra and geometry classrooms. When we narrowed our focus and examined whether the effect of technical math classrooms depended on level of student achievement at pretest, we found that math achievement for higher achieving students improved more if they were in technical math classrooms instead of geometry classrooms. In addition, we found that higher achieving geometry and algebra students' math attitudes actually worsened from pre- to posttest, but higher achieving technical math classroom students' attitudes stayed about the same. Taken together, these findings suggest that assignment to technical math classrooms may improve math attitudes on average, and this effect may be attributed to technical math classrooms' ability to attenuate a decline in the attitudes of high achieving students. In addition, assignment to technical math classrooms may lead to greater improvement in math achievement among high achievers, relative to their counterparts in geometry classrooms.

Limitations. There are three key limitations to be considered in the interpretation of these results, including: (a) the selection of the comparison groups, (b) the missing data which required imputation, and (c) the low numbers of participating teachers. Because this project was a research and development project, a random selection of classrooms for testing was not a possibility. Use of comparison classrooms for a quasi-experimental design was a second-best option; however, no adequate comparisons existed for the newly developed problem-based technical math course. This challenge was coupled with the limited options of mathematics course offerings in small districts that could be used as comparisons. The solution was the selection of math courses in the same school in which the students would have enrolled if there were no technical math course option; the assumption was that the students would be closely related in ability to others who enrolled in the course. However, this assumption may have been confounded by the enrollment of non-CTE students and underperforming students in the technical math courses.

A second limitation was missing data. A potentially large amount of data was missing and likely introduced a substantial amount of uncertainty into the process of imputing missing information. To address this issue, we used multiple imputations, a state-of-the-art method for handling missing data that incorporates imputation uncertainty into the analysis model, producing more conservative standard errors (Enders, 2010). Our approach to handling missing data is described in more detail in the section *Missing Data Analysis*.

Finally, the number of participating teachers was too low to conduct a classroom level analysis, limiting analyses to the student level. We were able to control for teacher differences by using the complex function in MPlus to account for nesting of students in classrooms and then by using dummy variables to account for teacher differences. This prevented teacher differences from contaminating our student level effect estimates, but we were not able to determine which teacher characteristics might have accounted for observed teacher effects. In addition, while we controlled for teacher differences, we could not account fully for variation in the implementation of the units. For example, teachers reported pausing for math enhancement lessons, shuffling lessons within the units, and de-emphasizing some units over others. Indeed, this autonomy was available to teachers by design. With larger numbers of teachers, future studies may be able to determine which teacher characteristics or behaviors are important to changes in math attitudes and achievement.

Despite these limitations, this study's findings provide the first evidence that technical math classrooms may provide a method for improving math attitudes, particularly among high achievers, which does not harm student achievement relative to business-as-usual math instruction. This finding is promising because past research indicates that improvement in math attitudes has lagged positive effects on later occupational outcomes. Thus, technical math classrooms may produce better long-term occupational trajectories through their effects on secondary student math attitudes. Future research can bring longitudinal data to bear on this possibility. This study's findings also suggest that technical math classrooms may produce greater improvement in math achievement of higher achieving students as compared to some traditional math courses. Taken together, our results suggest that future research on the efficacy of assigning students to technical math classrooms would be useful.

The Teacher Experience

The project leaders were especially interested to learn about the process of developing and teaching the new technical math course. Therefore, they gathered qualitative data throughout the research and development phases to capture the teachers' perspectives and experiences. Focus group sessions were conducted at the conclusions of both Phases 2 and 3. Teachers were asked a range of questions about their experiences using problem-based learning (see Appendix G). These discussions were taped, transcribed, and analyzed thematically; the emergent themes were triangulated with data from post-project surveys, online unit reports, and field notes from the professional development sessions and webinar meetings. The themes that emerged from the teachers' experiences in Year 2 were further validated and explicated in Year 3.

A "Productive Struggle."

The overall experience of the teachers throughout the project was both positive and optimistic. A number of the participants had previously participated in Math-in-CTE professional development and were especially anxious to realize a parallel effort in mathematics: as one participant expressed early in the project, "I was really excited and still am because after going through the Math-in-CTE, my thought process is, 'Can't we do that in reverse?'"

From its inception, the project leaders modeled the problem-based approach as they facilitated the course development process. In the course development phase, the professional development activities were intentionally planned and structured to allow the teacher development teams to identify, define, and develop the units of instruction within the technical math course. The development teams were provided templates and resources; however, no prescribed curricula were used.

While the teachers embraced the project with enthusiasm, the process provoked a *productive struggle* (Hiebart & Grouws, 2007; Strother, Van Campen, & Grunow, 2013) that pushed the math teachers out of their comfort zones: "I really enjoyed it, but it was frustrating…at times. I just wanted to teach math. It's so *comfy* there…" Unlike teaching a traditional course in which the math was neatly scaffolded, the PBL approach demanded simultaneous use of multiple and varied math concepts and principles to solve the real-world problems. During the implementation phase in Year 3, a math teacher who had joined the project in Year 3 likened the experience to "being a first-year teacher all over again."

Adding to the struggle was the introduction of an entirely new field of knowledge as the context in which the math instruction was situated. The math teachers knew little or nothing about the manufacturing, construction, and engineering content, as one noted with considerable humor:

> You knew more than next to nothing. But honestly, that part of having to research the [CTE content] to me was fun. I always like to learn…but to be able to develop something which I really absolutely knew nothing about…that was the *funnest* [sic] part to stretch myself a little bit!

The teachers were quick to note that engaging in the project was an exciting and worthwhile experience. They persisted in the process because they perceived an ultimate benefit for their students:

> …if you really want true collaborative learning to occur, as like we do with our students, we modeled it here...when our students were struggling with concepts it's like I struggled with the concept and I got through it….You're going to struggle and it's okay to struggle.

The result was a teacher-generated math course that came from the productive struggle of teachers who engaged themselves in the same processes they would ask of their students.

An Emergent Community of Practice.

Wenger et al. (2002) suggested that communities of practice cannot be formed; rather they are fostered through structuring of work around a common mission. The professional development format, which facilitated cooperative activities among the math-CTE teacher development teams, provided an opportunity for them to experience proximity with one another; they were privy to one another's conversations and were frequently observed to be moving from table to table to help one another solve problems. "It wasn't done in a cubicle," as one CTE teacher observed, "We had [a] 360 view of everything that was going on all at once."

The math and CTE teachers alike appreciated the collegiality that formed in the sessions, as another noted, "I really enjoyed the process, both in our large groups and with our webinars.

It's been invaluable having people to talk with going through the process." Those who participated in the development phase of the project described a growing sense of community, characterizing the experience in this way:

> …[there were] the social norms we agreed to when we started this – of civility and kindness [laughter]…, and there was a camaraderie and rules that were agreed to. … I have been in other places where it's *you don't laugh.* … And here, that was acceptable, and that was actually part of the comic relief and people found ways of adding a little zinger here or there… very, very important especially in a struggling learning challenge...

The teacher partnerships. The starting point for the community of practice was the formation of CTE-math teacher development teams in first phase of development. These pairings were critical to the initial development of the units; content expertise of the CTE teachers was foundational to the development of the problems, questions, and instructional activities, as described in this comment:

> I don't think you could do it without…a team. I think that [my partner] and I both being committed to this concept of applied math I think was really important. I knew she cared about it and we both cared about it so that we were willing to get through the hard parts…

The importance of commitment to the mission resonated in conversations among the teachers throughout the three years. One of the newer teachers attributed his success to mentoring from the experienced teams and the support of his CTE partner:

> It really helped coming here and watching you guys do the lessons before I went back and did the lessons. That really helped a lot. I appreciated [my CTE partner]. We would get together and just kind of visit and make sure I'm doing it right.

As the project evolved in years 2 and 3, not all teachers were able to continue their participation, and variations in the team configurations occurred. Some math teachers were paired with CTE teachers; others were not. One CTE teacher who lost his math partner continued with the project to provide support to math teachers who did not have a CTE partner, thus fueling the need for the greater community of practice. Additionally, the need for partnership lessened for more experienced math teachers who had the benefit of the early development process with CTE teachers. In the end, the teams evolved into a greater community of practice as the teachers moved beyond their partnerships to facilitate the group discussions and assumed a supportive role for one another.

Growing respect among the teachers. With the emergence of the community of practice also came a growing sense of respect among the teachers. A CTE teacher partner commended the motivation and commitment of the math teachers who engaged themselves in this new approach:

> The math teachers that we had in some ways were very, very unique and very special, was that they all kept swinging to hit the ball … nobody stopped swinging the bat. And so that should be recognized that every math teacher… went outside their comfort zone, just kept going.

Conversely, a math teacher made this observation about the CTE teacher partners:

> Working with colleagues has been invaluable. … It was so fascinating to talk to CTE teachers and hear what they use. …I thought that was invaluable. We don't have that enough where we get out of our little box of our comfort zone of [math] teachers.

As the project transitioned into the testing year, some of the teachers in development teams dropped off and other new teachers joined. Project leaders paired the experienced development teams with the new teachers to serve as mentors in the implementation process and to foster a sense of belonging. The full implementation of all nine units of the yearlong technical math course was a demanding experience, yet by the end of the project, the teachers had begun to speak in terms of *family* and the importance of working together:

> I agree, it was really difficult to get started. I really liked the sense of family and the collaboration that we had working together. …We're speaking of here and we've all kind of touched on it how we like working together and how it's changed us.

Teaching Mathematics using Problem-Based Learning.

The math teachers who volunteered for participation in the project in all phases of the project were anxious to use the PBL approach and even thought it was exciting to learn a different way to teach mathematics. As one described it: "It's easy for me in a sort of traditional math direct lesson…to get as bored as the kids do occasionally. And so I found [PBL] stimulating." While they embraced the approach, the actual process of teaching in the context of CTE posed some real challenges, as another disclosed:

> The electrical unit was…just mind-boggling for me. It was just…when I first looked at it, I said, "Ah. How are we really going to do this?"…I knew absolutely nothing about [electricity] whatsoever, and that was a challenge.

Teaching with "stuff." With PBL came the need for the math teachers to teach using construction-type supplies and equipment such as wood, foam core, glue, cutters, measuring devices, multi-meters, wire, batteries, bulbs, pressure plates, etc. The math teachers faced a new dimension of instructional planning, which one mused was "a whole different category of finding stuff." An amusing legend among the teachers fondly named "The Box-Cutter Debacle," illustrated the nature of the challenges faced by the math teachers as they led groups of students in PBL activities. The cutting tools originally purchased by the project were not holding up to the cardboard. Conversely, the cardboard used by some of the teachers was too flimsy for cutting. The less-than-successful outcome became fodder for many a joke. One CTE teacher partner observing this activity suddenly realized that simple, but essential, skills were missing; that teacher eventually created videos of basic tool demonstrations for the math teachers and their students. The legend, however, remains.

Adding to these challenges was the task of organizing classroom space to construct and store the projects. Once orderly math classrooms took on the look of active laboratories. One CTE teacher warned his partner, “Your room is going to look like this [a mess] and you’re going to need storage…” Another who observed the condition of her partner’s classroom, humorously made this point:

> He was this person that is so neat and organized. He could not let that piece of paper stay there. …Even two weeks ago I said to him, “Wow look at your room.” He said, “This class taught me to get over it. You just have to have things all over the place and you have to collaborate with the kids in their group work.”

The CTE teachers proved invaluable as they assisted their math partners in locating donated items, organizing their classrooms, arranging for storage, and practicing construction techniques.

Managing cooperative learning groups. The cooperative learning groups used in PBL also added a new dimension to classroom management as the teachers learned “how to keep everybody on track in a chaotic classroom.” One of the greater challenges of teaching the units was to manage the group work:

> One of the struggles…was that kids would zoom ahead and then they would either become a discipline problem or lose interest. And so that’s the difficulty: What do you do with those kids? Do we have other physical projects to make? Well, then you got a materials issue. Or you put them online, maybe some teachers don’t have a classroom that’s got computers or access, but I don’t think those problems should stop a school or a teacher from trying to do this. It’s just something they need to be aware of.

Another described generating strategies to increase students’ accountability in the groups:

> I really struggled through the projects of who was pulling their own weight. So in the capstone project I had a log and it was just something I simply made up that said Monday, Tuesday, Wednesday, Thursday, whatever and then I had the list of all the students' names. They had to write in what they had done that day.

"It's like you have to go forward no matter what," yet another commented. "If the group isn't there you're required to go forward and you've got to get ahead of some of those things because otherwise you'll get bogged down."

Sequencing the mathematics instruction. The PBL approach required a more complex conceptualization of instruction to accommodate the CTE context *and* simultaneously, the ordering of the math concepts and principles required to solve the problem. This observation made by a CTE teacher illustrated the dynamic nature of the process:

> I was thinking that the hard part seemed like the organizing of this thing. If we were building a building….I know we're going to do this, this, this and this. Then the math person…they're teaching a math course and it will go like this, this, this and this. Well, here we are teaching this thing that's not the math course and not the building [course] and we're trying to figure out the order of things so that it can meet the needs of both things. That seemed difficult.

Because each of the units was guided by a central question instead of a math textbook or curriculum, the math content was sequenced differently and required thorough preparation. One math teacher described: "We had to rely on our own abilities. …It is a different kind of class." The math instruction was no longer "linear" and required considerable adjustment:

> You had to really prepare, especially if you had a lab that was going to be set up. For me as a math teacher that was an adjustment. I really could fly by the seat of my pants but not in this class.

The sentiment was echoed with some optimism by one of the newer teachers: “I did more prep and planning for this class than all of my other classes combined. But next year I don’t think it will be like that. It was just because it was my first year.” Another reflected:

> I think project based learning takes a difference sense of time. It’s okay not to get something 100% done. …I think one of the big differences between a pure math class and an applied math class is [in] pure math that you can scribble it out real quick and you can get to the number but you don’t understand how you got there and you don’t understand why that number has relevance.

The tipping point – is it math or CTE? The focus on learning new CTE content and skills while effectively teaching math was a balancing act that required some adaptation to the instruction to meet the immediate needs of the students. This teacher admitted there were just some days where it was necessary to suspend the CTE and have a “math day:”

> … “Am I in a math class or am I in a CTE class?” And so I found several times when it came time to … some of the rigor of math, [I said] “Okay, it’s a math day. We’ve really got to get through this.”

Similarly, another teacher disclosed the tension of articulating the balance to the students:

> One of my challenges was trying to keep the connection…and field…to keep the connection clear to the students between the initial larger context, then the specific math, and then going back to the project … trying to keep continuity there. I found a lot of struggles with that….Is it math or is it CTE?

Authentic Assessment.

Teaching with a problem-based approach required changes in learner assessment, as teachers began moving away from norm-referenced methods to the use of criterion-referenced methods. This impacted the teachers' overall understanding of assessment as some engaged in authentic assessment for the first time:

> The bridge-making rubric opened my eyes to a completely different way of assessing math knowledge than I had used before, and I found that really helpful to realize how much of the problem in a standard testing situation was related to reading problems and being able to have it be an oral test and physically showing me things made a world of difference with several students.

One teacher noted how assessing the students through questioning was "one of the most favorable aspects" of the approach. The teachers also discovered through authentic assessment how to know if the students really understood what they had learned:

> … it was a real eye-opener to me sitting down and have the student try and show you specific things on the project that they just did, and if we can assess as many things that way as possible, I think we have a true read on the connection between the math and the CTE. That was just phenomenal.

The teachers also observed the power of self- and peer-assessment. One teacher observed how the students began to question and check each other, and "quizzing each other on that whole lesson."

There was also a realization on the part of the teachers that the use of authentic assessments such as those created for the bridge unit were capturing a deeper level of math learning:

> I think it's an active perception that this one sort of changed people's ideas of what assessment could be in some ways…something we realized, that you could do this in a very different way and get at the same thing and maybe even deeper than what you did before.

As another summed, “I think there was more thinking in this course than in some of our traditional courses.”

The grading dilemma. While the strengths and benefits of authentic assessment were evident to the teachers, the issues of grading became a point of discussion and concern, especially in Year 3:

> … how do we grade it and does anybody here feel like when they graded it they felt that what they gave really represented what our students knew and what they learned? I’m not sure mine did. I don’t know if I graded it properly. … What does that all look like even though we have rubrics for different things?

Other questions arose, such as: “How do we assign grades for projects?” “How do we grade group work fairly?” “How do we balance the grading of individual work with that of group work?” “How is this related to proficiency based grading?” The teachers debated how to grade participation with fairness, eventually linking it to proficiency and students’ accountability: “part of your proficiency is showing up and working as part of your group… you’ve got to be here to do the learning.”

Each of the schools involved had their own parameters and policies for grading, which the teachers had to mediate with the authentic assessments required for PBL. That tension is noted here:

> … from a practical standpoint from an administrative level, we can’t go more than about two weeks before we have grades in the grade book, and so if you have a fairly long unit and you don’t assess until the end … so maybe not just a necessity that is manufacturing, but the fact that it’s at the beginning of the course, there may need to be some smaller grading.

Another faced this reality: “We get hammered on it because I have basically three per nine weeks, so it may be three weeks into the term before there is a grade and people scream, ‘Well, what’s their grade?’” The teachers themselves mediated the grading dilemma during the testing year and identified the need to develop smaller, more frequent assessments for future use of the units.

Meeting standards. The teachers took seriously their responsibility to meet the needs of students in terms of what was required for state testing and for graduation. This same concern led the revision teams in Year 3 to reorder the units and give teachers the latitude to make instructional adjustments on behalf of their students:

> Well, sometimes there were gaps. I’m not sure we really looked at it from the standpoint of … what the math sequence would be as opposed to I think we looked at the technical sequence. And so there were times where all of a sudden we hit something math-wise and there’s this gap and there should have been something in between…

Teachers also met with a number of misperceptions about the course from administrators, parents, and students. Most concerns were related to the idea that the course was somehow “less than” other math courses:

> Somehow either in the communication about this course or just in students’ perceptions there was a sense of this is math redundancy or these are for the folks who didn't do well or something like that. I think we have straightened that up looking at our registration for next year.

Another concurred, saying, “the other thing too is perception of how is this going to help the student on the state test. Parents ask that question too. Is this going to be able to get my kid fit for the test?” While many of the teachers worked through this concern with their administrators, the challenges persisted, leading some of the teachers to recommend involvement of guidance personnel in future rollouts of the model.

Benefitting Students.

In spite of the instructional challenges they faced in teaching and assessing differently, the teachers did not hesitate to talk about the perceived benefits to their students. They spoke of increased confidence, increased engagement, and lessened fears. For many students, this course was the first time they were able to visualize the mathematics and make the connection of math to a real world application:

> I think it's the very first time kids actually see the physical relationship between a hypothetical number…and the physical reality that that math number can create or not create if you mess up. I think that's a really, really important for kids to better get a grasp of how math can actually work. I think that's part of the fear that they lose.

Increasing confidence and pride. One CTE teacher noted the increase in confidence and pride when the students displayed their projects in the school showcase. He made this observation about their growing math abilities and other students' recognition of their accomplishments:

> It was very interesting to see how kids that would not be leaders in any sense of the word … suddenly became the expert to go to…. And it didn't matter if it was the quietest kid in the school or someone that wasn't cool or…. the other kids went to them because they "knew." And it was … an amazing thing to watch.

He also noted that as the confidence built, their battles with math seemed to recede.

The competition to test the strength of the bridges at the end of that particular unit meant "bragging rights." Pride was building among many of the students who previously did not show interest in math, as a teacher shared, "…if you were the winner you … ruled the room. I mean, that was evident." Notably, it also provided an opportunity for those who did not "win" to still feel accomplishment in their projects, as another remarked: "What I thought was interesting was that [the students who] did not win ended up forming their own little “we’re failures but we did okay” group, which is different [than before]… you know what I’m saying?”

Increasing engagement. While some students expressed initial objections and fears about the technical math course, the teachers reported students becoming excited about learning. In one class, the students liked the activities so much that attendance was almost one hundred percent every day: “They wanted to be there to continue building that. Math is usually just a hit-and-miss type thing. These kids wanted to be there.” Through the many stories depicted by the teachers, it was evident that students who would not otherwise have taken an interest in math actively engaged in the problem-based approach:

> I had four individuals this year that would … say that math is not their favorite subject. The way this course ended is that when we made the dollhouse …we had to still install it because we kind of built it in our tech wing but then we had to install it in a different location. These four individuals were the students who followed through and helped put it together once it was done. …They wouldn’t have done that in a math class. …The real awesome thing was it was after the term was over. So those were the four kids who were coming back to finish it after the course was over. That’s what’s so awesome about it.

Another teacher shared a similar story:

> There were two kids I know of … they figured a way to stay in school to finish off the applied math class and that’s the only reason they stayed. They needed it to graduate. They got rid of everything else. They did everything and they passed that class. It was very interesting to see…

There was also evidence that the problem-based approach was calling students into a level of accountability they had not experienced before. For instance, students could no longer complete a pencil-paper test and be done with the unit, as this teacher described:

> [Some students] were used to doing a problem on a piece of paper, and if the result didn't work out, they could move along and just push that non-success into the non-success area and never have to deal with it again. …when you're doing the math that we're trying to do, you had to get it right before you could go do the [CTE] activity, and that is a unique concept.

There was some discussion among the teachers about students who were not enrolled or interested in CTE, but were placed in the technical math course anyway. One teacher reported some initial resistance on the part of his female students because they felt it was a "boy's" class, but noticed increasing engagement as the course progressed:

> I actually think that the young ladies that we had in our classes enjoyed this class as much as the young men. I wasn't sure they were going to have that buy-in because I just wasn't sure. So it's been really exciting to see some of these girls really enjoy it.

Overall, the teachers reported that the students responded favorably to the highly integrated learning activities, especially as the units come together in the capstone project.

Helping students of differing abilities. The technical math course was designed to maintain the rigor of the mathematics, as one teacher concluded, "It's a class that fits all levels [of students] and is probably best handled that way." This observation was also verified in the mapping of mathematics standards that were addressed in the course (see Appendix E). However, the teachers also expressed considerable hope that the course would help students who just do not learn well in traditional settings:

> I was excited for this set of lessons because the students that I work with … who don't do well in traditional school need a hands-on component to make math relevant, and I was hoping this would do it for them…

In fact, one teacher who kept classroom-level data on the students reported an increase in achievement of the lower-performing students: “This year the class was comprised of 50% students who were on IEP’s for math. Seventy-five percent of them passed the state test.”

While consideration was given to meeting the needs of students who struggled with math, there was also some concern about the impact of the instruction on students with higher-level abilities. Would they be bored or underserved? The teachers reported a mixed response. Some students thought the course was easy; others were challenged by the applications. One described his students’ resistance and preference for traditional math instruction, along with his response:

> I had a wide range of student abilities but watching really bright kids get really frustrated because it wasn’t that really linear mathematics…For some of these kids it was kind of the issue of, look, my calculator says this and here’s the ten digits on the display. It’s like, okay, that sounds really good. Take that to your bank and see what happens. How do you think your way through this problem?

One student who reportedly “flew through the project,” was asked by the teacher if the unit was too easy. The student responded, "Oh no, this is the best math class I have ever had.”

Real-time transfer of learning. The teacher teams also shared many stories of their students extending their newfound knowledge beyond the classroom. One teacher shared an amusing story of a young woman who went home and observed the deck stairs had been built incorrectly. Another relayed a story about a student who had learned to use multi-meters in his class and was now requesting them for application in another class:

> Two years ago or three years ago in my high school only some of my guys knew what a multi meter was. Now they’re cracking them out in all kinds of classes. I freaked out the last couple of weeks of school because I have a drawer that I keep some in and share. A

kid came up and said, "I need six multi meters. …We need to do something and we told them they could do it this way."… It was a biology class.

A CTE teacher described how the students' improved math skills were showing up in his classroom and "knowledge was shooting back and forth." He continued, "It was pretty cool. Also the tape measure skills were way better, totally. …I could tell them, look, I need twenty of these things cut at $5/16^{th}$ and $7/16^{th}$ or whatever and they were right on, all of them, the entire stack perfectly right. It was a big deal."

The authentic application. The final unit in the technical math course was a capstone project that engaged the students in the application of all they had learned. As one teacher shared, "what made the last project so fun for our kids is that real wood, real hammer, and real nails." And, in the end, it all made sense to them:

> I really liked to see the kids how they took pieces of each thing and put it all together at the end for the capstone project. …So the kids wanted to build the capstone project as bunny houses. So they took a lot of planning and a lot of designing and they got into groups of five. Then they all built three different bunny houses. It was kind of neat to see the rabbit go in there and the kids get all excited. I enjoyed seeing them take portions of the bridge, the floor plans. There were just so many different units that we put together for that one culminating activity. They really enjoyed that.

Final Thoughts.

By the conclusion of the project, the teachers had developed a sense of ownership in the project. They frequently led their own discussions and freely engaged in critique with one another. Due to primarily budgetary constraints, not all could continue to offer the technical math course; however, the post-project surveys indicated that every teacher intends use the units "quite a bit" or "a great deal" in their future instruction, as this teacher explained:

> The thing that I liked was the concepts that I teach every day in all of my math classes and then how it bridges the gap with CTE. We're not going to be able to teach this class next year just because of numbers. Our school is small and it's getting smaller. But some of these concepts will be in my math classes, especially geometry next year.

The teachers also expressed strong support for a rollout and expansion of the model and talked about ways new colleagues might become involved in the future. As a group, they negated the idea of distributing the course curriculum without involving new teachers guided in learning the process by seasoned facilitators with PBL experience:

> I think it's going to be important to walk them through our unit still like we did for each one of us and do a demo so they get a little bit of the hands-on piece that you're talking, and maybe that's one of those areas we can actually make better by training the rest of us how…

Some suggested the model offers a unique and viable opportunity to engage community partnerships with business and industry. Others made the connection to STEM initiatives and noted the opportunities for rich enhancement of mathematics with authentic applications. As one noted, "the reality is…there's a lot more to this."

This final comment from a teacher in the development phase received enthusiastic agreement from the teachers; its sentiment was echoed by others in Year 3:

> I have one last thing. Just to personally say thank you to Tom [project leader] and everyone else in the State of Oregon for the opportunity… it is nice that there was some kind of vision. …I think that is something that needs to be recognized because it has…changed my school for the better…

The Student Experience

At the conclusion of Year 2, the project leaders interviewed students from each of the schools that implemented the course for the first time. The leaders were interested in learning about their experiences in learning math differently, with the ultimate goal of using their input to improve the course for Year 3. Subsequently, five students from each classroom were invited to participate in a personal interview with a representative of the state.

The interviews were brief – about five to ten minutes each, just long enough to ascertain their overall experience (see Appendix H). In total, 32 students were interviewed. To ensure students with a variety of educational backgrounds and interests were interviewed, the researchers asked teachers to request volunteers and identify students who (a) excelled in math or in the course, (b) struggled with math or with the course, (c) had a turn-around story, (d) had a CTE background, or (e) had no CTE interest. Several notable themes emerged from these interviews. For reasons of privacy and confidentiality, student and school information are not disclosed; this section contains an aggregated version of what they shared.

I like learning this way; I'm a hands-on learner. The majority of students interviewed expressed how much they liked the course, echoing the observations of their teachers. They particularly talked about how much they enjoyed building things and having "hands-on" experiences. One student labeled it "learning outside the textbook." Some were quite articulate in their perceptions of the experience.

Many genuinely appreciated the opportunity to learn math in this way and talked about how they thought more courses should be taught this way. One student noted how his grades went up when given the opportunity to be in the class. Some students liked the course because they did not have traditional homework assignments. Another student who liked math and had already completed graduation requirements took the course to take additional math. Some wanted a few more projects, some wanted a few less, but almost all students interviewed mentioned how interesting and fun the projects were. They were also proud of the structures they had created, frequently noting the size, the conditions, and the processes of creating them. The Bridge unit was mentioned most often, and the students were anxious to talk about the strength and collapse of their bridges.

Many students did not know that the course was “different” until they were into it; however, this did not seem to bother them. In fact, many of the students commented that the course was not easy. One student who assumed the course was for “lower” math found it to be both interesting and challenging.

It was noteworthy that some students seemed quick to express their limitations in identifying themselves as a “hands-on” learner or saying that “I am better with my hands.” This may raise some questions about how they came to assess themselves in that way, what it means when they use the expression, and how the project leaders may choose to frame and express the rigor of the course in the future.

Teacher skills and engagement matter. It is of interest that a number of students observed their teachers’ engagement in the course or commented on how the teachers were teaching differently. Their attention was captured when the teacher was heavily engaged in the process with them. Several students from one class specifically mentioned how much they appreciated their teacher who always helped them and “helped even when help wasn’t needed.” Another student from a different school noted how great it was to have a teacher who “did not sit behind the papers at his desk.” Yet another contrasted the approach of former teachers who “show you how to do one or two” problems and “leave you to figure out the rest on your own.”

The PBL approach calls for a teacher to have a comprehensive knowledge of the content as well as the process of teaching in context; when that goes awry, students notice that, too. A few students noted that their course units seemed unconnected at times or “jumped around.” One attributed the experience to the teacher’s newness with the lessons, but admitted to “learning a lot in the end” though it was a “complicated” experience. However, reasons for the disconnect were also attributable to the teacher’s need to balance the CTE and math in the curriculum. Each of these observations gave some credence to the extended PD time needed to help teachers know and understand a PBL approach and to practice teaching differently before taking it to the students.

We like working in teams. Simply put, the students liked working in teams on the projects. They commented frequently about how much they enjoyed working together to accomplish the projects. They provided a full array of reasons for this, including shared workload, learning from each other, getting to know others, and being able to work with friends.

A few noted that the projects became a bit boring or time was wasted when they were finished ahead of others. More than one student suggested providing students with more options, so those who were working more slowly would not hold them back. This echoed the sentiment of the teachers and should be given full attention in future implementations of the model.

I can see the life and work connections. Most of the students interviewed clearly detected the connections of the course to their current and future lives. One student was rather eloquent in expressing how the projects “kept them going, kept them in school, and because of that would keep them going in life.”

There were mentions of how the course linked to current jobs in family businesses in the trades, construction, and agriculture. Others perceived its usefulness in their future military- and engineering-related careers. One simply related it to having a good family life ahead, and another confirmed, “It’s just a good experience.”

It's not a one-size-fits-all model. It is important to report the outliers in these interviews, because they remind us that any one model of teaching is not necessarily the answer for all. Two students expressed continued disinterest in math; however, both noted that they thought some of the projects were "fun," but this did not change their perspectives on math. The interviews revealed two other students who loved math but were neither interested in nor challenged by the projects and activities.

Conclusions

The Oregon Applied Academics Project was a three-year research and development effort that forged a problem-based approach to the instruction of mathematics. The project was conceived as process through which to develop a course that enhanced the mathematics learning of students participating the Career and Technical Education pathways related to engineering, manufacturing, and construction.

Findings revealed that, overall, the math attitudes of students who participated in the technical math course improved more than their peers taking traditional algebra and geometry courses. While students in technical math courses began the year with poorer math attitudes than students in traditional math courses, by the end of the year their math attitudes were better than those reported by the comparison students. In addition, the results of this study indicated that math attitudes for technical math students with high levels of pretest math achievement remained about the same during the year, while math attitudes for high achievers in traditional math courses worsened. These results were consistent with the qualitative findings from student interviews conducted in Year 2 and subsequent anecdotal evidence collected in Year 3. In summation, a majority of the students reported that they enjoyed the context-based PBL approach to math and benefitted from the experience of working on the real-world applications.

While overall improvement in math achievement was not greater for technical math students than their counterparts, analysis of ACCUPLACER® (College Board, 2012) scores revealed that students taking the technical math course gained math skills as they participated in the course. Furthermore, results indicated that technical math students with high levels of pretest math achievement improved during the year, while math achievement remained about the same for their counterparts in geometry classrooms. Finally, analysis of the mathematics content within the units of the course met the rigor of Oregon’s high school math standards.

Perhaps most compelling was what project leaders learned directly from the teachers through the focus groups, surveys, and overall interactions with them over the course the project. They indicated satisfaction with the model and observable benefits for their students – a sentiment that was echoed by the students themselves. All teachers in the project reported they will continue to use the units in the future whether or not the full course is offered in their schools.

Emergent Principles

Several principles emerged from Oregon Applied Academics Project that echoed those first recognized in the Math-in-CTE research (Stone et al., 2008). These principles illuminated aspects of the model that *made it work* and the results of this project suggest they provide valuable guidance for future implementations of the model.

Establishing partnerships between math and CTE teachers. The pairing of CTE teacher partners with mathematics teachers was considered a non-negotiable aspect in the early phases of a project of this scope. The CTE teachers' expertise was crucial to the identifying the real-world problems and situating the big questions in the context of CTE. Furthermore, the mathematics teachers needed assistance in learning about (a) the skills and safety features associated with laboratory activities, (b) the acquisition and handling of tools and supplies, and (c) the language of the work world. As the math teachers became more experienced and skillful with the context, they needed less help from their CTE partners, yet still benefited from access to their CTE expertise.

Fostering a community of practice. Wenger (1998) suggested that communities of practice are not formed, they are fostered; they emerge when the conditions are right. Teachers working together with a common, agreed-upon mission is one such condition. Considerable theoretical support exists for the value of communities of practice in promoting lasting change in practice (Wenger, McDermott, & Snyder, 2002). These theories were validated in the Math-in-CTE study (Stone et al., 2006) when communities of practice emerged as an unintended outcome of the study. In the Oregon Applied Academics Project, signs of the emergence of a community of practice were observed among the teachers who worked together to create the technical math course. These signs included the growing levels of respect and trust among the math and CTE teachers displayed through efforts as simple as sharing resources with one another and as complex as engaging in honest critiques of the units.

Maintaining mathematics as the central feature of the problems and questions. While situating math learning in an authentic context, the goal remained to effectively teach mathematics. As the math teachers learned to use the PBL approach, evidence showed that the instruction could reach a tipping point when the CTE activity overtook the mathematical purpose of the course; those were moments when the math instruction was lost in completion of the lab activities or projects. Making the call to recognize that tipping point, draw back, and regain the balance was incumbent on the teachers throughout their instruction.

Adapting the instruction. The teachers who participated in this study monitored their students' progress and adjusted instruction to their needs. However, they also experienced competing external pressures that challenged the implementation and sometimes resulted in further adaptation. Some examples of these pressures were: (a) state testing expectations and/or standards, (b) cultural or community expectations and needs, (c) physical limitations of classrooms, (d) content or curricular demands, (e) perceptions about students' abilities, and (f) the time it takes to change practice. Therefore, a pedagogic model that was systematic and intentional, yet flexible and responsive, was essential to develop.

Recognizing we are teaching mathematics in context; we are not CTE teachers. While the math teachers in this project stepped up to meet the challenge of teaching in context, they suddenly found themselves in unfamiliar territory. They conducted laboratory activities involving use of construction materials and tools. In one respect, these activities were fun, but, in another respect, they were time-consuming and difficult. Math teachers were faced with the task of learning new skills in order to teach the embedded mathematics and lead students in the development of their projects. They also were faced with a new level of safety considerations not often required in math classrooms. These challenges again point to the importance of engaging teachers in robust professional development that allows for the development of confidence and skill in adopting a new approach to teaching mathematics.

Final Words

Collectively, the findings from this project provide evidence that a problem-based technical math course is do-able for teachers and beneficial for students. The findings also demonstrate that situating mathematics in context is a viable option through which to meet state-required standards without losing rigor in the mathematics instruction.

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Appendix A

Unit Template

Oregon Applied Academics Project
Unit Plan Template

The Real-World Problem or Big Question:

Unit Name:

Unit Goal/Objectives:

Authors:

Lesson (Content):	CTE Concepts Addressed:	Math Concepts Addressed:	Math Standards Met:	Authentic Assessment:
1.				
2.				
3.				
4.				
5.				

Appendix B

Lesson Template

Oregon Applied Academics Project Lesson Template

Lesson Name/Number:	**Unit Name:**
Lesson Objective:	**Authors:**
Math Standards Addressed:	
Supplies Required:	

Elements of the Applied Lesson **(Develop/script the lesson in each of the boxes below)**	**Teacher Notes** **(In this column, add insights, resources, links, references, answers to complex problems, etc.)**
1. Introduce the "real-world" problem or "big question" we will address with mathematics.	
2. Assess students' pre-knowledge of the mathematics concepts and principles required to address the real-world problem or big question.	
Transfer of Learning: 3. Instruct the applied (contextualized) mathematics concepts and principles embedded in the problem or question.	
Transfer of Learning: 4. Reinforce the embedded concepts and principles with other, related applications.	
Transfer of Learning: 5. Present the embedded concepts and principles as they would be learned in a traditional math class.	
6. Provide students with authentic assessments through which they demonstrate their ability to solve the real-world problem or big question.	
7. Assess students using traditional mathematics assessments that address the Oregon standards.	

Appendix C

Critical Friends Process

Critical Friends Process

Oregon Applied Academics Project

The Critical Friends process (Bambino, 2002) is a way for you, as colleagues, to provide constructive feedback to one another in a non-threatening way. This is a reciprocal and respectful process focused on the unit and lesson development. The intent is to support our common goals of improving the quality of our work, and readying the units and lessons for use in the upcoming year.

Your responsibilities are to:

1. Deeply examine the lessons and the unit as a whole (individually and as a team).
   Guiding question: *What would I need if I were teaching this unit or lesson?*

2. For the unit and each of the lessons, prepare **thorough written feedback.** (Feedback should be written by both team members – math teacher and the CTE teacher.) The written work will be handed off to your Critical Friends team for their use in refining the unit and lessons.

   - Provide "cool" feedback for areas that will benefit from further work.
   - Provide "warm" feedback for what you consider the strengths of the lesson.

   Examples of written feedback may include:
   - Questions for clarification of intent or purpose of aspects of the lesson.
     Ex: What do you mean by…? What is the purpose of…?
   - Questions for clarification of content or approach
     Ex: What do you intend…? What do you mean by…?
   - Questions to elicit more thought on a particular aspect of a unit or lesson, e.g. choice of instructional strategies, use of resources, etc.
     What if…? Have you thought about…?
   - Identification of redundancies and gaps
   - Suggestions for resources
   - Suggestions for improvements
   - Encouragement
   - Congratulatory comments
   - Other…

4. As a team, discuss your thoughts about the unit and lessons, and provide verbal feedback to your Critical Friends team.

5. In turn, receive written and verbal feedback from your Critical Friends team.

Bambino, D. (March, 2002). Redesigning Professional Development: Critical Friends. *Educational Leadership, 59*(6), pp. 25-27.

UNIT Feedback Sheet

Oregon Applied Academics Project

Questions	Cool Feedback	Warm Feedback
Is the "big question" or "real-world" problem evident? Is it driving the unit?		
Does the unit overall stay situated in the "real-world" problem or "big" question?		
Are the goal and objectives of the unit clearly presented?		
Does the unit align with standards and diploma requirements?		
Is the unit coherent from beginning to end – is it a sensible whole? Do the lessons progress in an understandable way?		
Does the unit overall encourage problem-solving and depth of understanding?		
Does the unit overall address the diverse learning needs of your students?		
Is the unit ready for instruction by other teachers?		
Other feedback		

LESSON Feedback Sheet Oregon Applied Academics Project

Questions		Cool Feedback	Warm Feedback
Introductory Elements 1-2: Establishing Context	Does the lesson introduce the “real-world” problem or “big” question? Does it point back to the intent or purpose of the unit?		
	Does the lesson introduce the mathematics in context?		
	Does the lesson introduce math vocabulary through the math embedded in the CTE context?		
	Does the lesson offer a variety of methods for assessing students’ pre-knowledge of math?		
Instructional Elements 3-5: Transfer of Learning	Does the lesson clearly work through the steps/processes of the math embedded in the CTE context?		
	Does the lesson offer multiple forms of the embedded math within the same context?		
	Does the lesson reinforce the embedded math with related applications?		
	Does the lesson present the mathematics, as it would look in a traditional math class?		
	Is the lesson coherent from beginning to end? Is the same math concept stranded through the elements?		

Lesson Feedback, continued

	Questions	Cool Feedback	Warm Feedback
Elements 3-5, cont.:	Does the lesson effectively bridge the language of math and CTE?		
	Does the lesson in its entirety provide for differentiated instruction?		
Assessment Elements 6-7	Are there opportunities for students to demonstrate what they know and are able to do?		
	Does the lesson provide well-developed, authentic assessment items?		
	Does the lesson overall encourage problem-solving and depth of understanding?		
Overall Feedback	Are the supporting materials and resources sufficient to support the lesson?		
	Are the lesson scripts and teacher notes sufficient for supporting instruction of the lesson?		
	Overall, is the lesson ready for instruction by other teachers?		
	Other feedback		

Appendix D

Oregon Applied Academics Project
Teacher Participants

TEACHER NAME	SUBJECT	SCHOOL
Luke Larwin	Math	Bend HS
Gavin Meyers	CTE (Drafting)	Bend HS
Ian Rondeau	Math	Churchill Alternative HS
Lee Kounovsky	CTE (Construction)	Churchill Alternative HS
Allen Bruner	Math	Colton HS
Amy England	Math	Coquille HS
Don Swenson	CTE (Manufacturing)	Coquille HS
Krin Hunt	Math	Crow Middle/HS
Tina Dworakowski	CTE (Construction)	Crow Middle/HS
Ruth Patino	Math	Estacada HS
Nick Lupo	Math	Estacada HS
Cliff Brown	CTE (Manufacturing)	Estacada HS
Ted Yates	Math	Gladstone HS
Lynnda Prom	CTE (Engineering)	Gladstone HS
Troy Morgan	Math	Heppner HS
Dave Fowler	CTE (Construction)	Heppner HS
Rachael Poole	Math	Lebanon HS
Lindsay Whitcomb	CTE (Agriculture)	Lebanon HS
Mark Aerts	Math	Molalla River HS
MacKenzie Behrle	CTE (Agriculture)	Molalla River HS
Richard Berenson	Math	Toledo HS
Peter Lohonyay	CTE (Construction)	Toledo HS

Appendix E

Oregon Applied Mathematics Project
Curriculum Standards Alignment

The curriculum developed for the Applied Academic Research and Development Project was originally aligned with the Oregon Mathematics Content Standards. The development team of teachers completed this alignment before testing the curriculum in the classroom. Adjustments will be made to the alignment during the summer of 2012 to accommodate what was learned during the teaching experience. The alignment to the Common Core State Standards in Mathematics is based on a crosswalk between Oregon Content Standards and the Common Core State Standards.

Unit Name and Description	Oregon Math Standards	Common Core Math Clusters
Manufacturing Students design and build a product (SOMA puzzle cube piece) that has to fit within the whole. Measure with precision in metric and standard units. Construct a two-dimensional net, scaled to size, and fold into a three-dimensional object.	**H.1A.2** Evaluate, compute with, and determine equivalent numeric and algebraic expressions with real numbers and variables that may also include absolute value, integer exponents, square roots, pi, and/or scientific notation. **H.1A.4** Develop, identify, and/or justify equivalent algebraic expressions, equations, and inequalities using the properties of exponents, equality and inequality, as well as the commutative, associative, inverse, identity, and distributive properties. **H.1G.1** Identify, classify, model, sketch, and label representations of three-dimensional objects from nets and from different perspectives. **H.2G.2** Identify and apply formulas for surface area and volume of spheres; right solids, including rectangular prisms and	**A.SSE** Write expressions in equivalent forms to solve problems. **A.CED** Create equations that describe numbers or relationships. **G.GMD** Explain volume formulas and use them to solve problems.

	pyramids; cones; and cylinders; and compositions thereof. Solve related context-based problems. **H.3G.3** Apply a scale factor to determine similar two- and three-dimensional figures, are similar. Compare and compute their respective areas and volumes of similar figures.	 **G.GMD** Visualize relationships between two-dimensional and three- dimensional objects.
Bridges Students use a bridge building project to understand properties of triangles.	**H.1A.2** Evaluate, compute with, and determine equivalent numeric and algebraic expressions with real numbers and variables that may also include absolute value, integer exponents, square roots, pi, and/or scientific notation. **H.1G.1** Identify, apply, and analyze angle relationships among two or more lines and a transversal to determine if lines are parallel, perpendicular, or neither. **H.1G.2** Apply theorems, properties, and definitions to determine, identify, and justify congruency or similarity of triangles and to classify quadrilaterals **H.1G.3** Apply theorems of corresponding parts of congruent and similar figures to determine missing sides and angles of polygons. **H.1G.6** Determine if three given lengths form a triangle. If the given lengths form a triangle, classify it as acute, right, or obtuse.	**A.SSE** Write expressions in equivalent forms to solve problems. **G.CO** Prove geometric theorems **G.CO** Prove geometric theorems **G.CO** Prove geometric theorems **G.SRT** Prove theorems involving similarity

	H.2G.1 Identify, classify, model, sketch, and label representations of three-dimensional objects from nets and from different perspectives. **H.3G.4** Apply slope, distance, and midpoint formulas to solve problems in a coordinate plane.	 **G.GPE** Use coordinates to prove simple geometric theorems algebraically.
Staircase Students design and build a small staircase while learning and applying concepts of slope and scale factor.	**H.1A.1** Compare, order, and locate real numbers on a number line. **H.1A.2** Evaluate, compute with, and determine equivalent numeric and algebraic expressions with real numbers and variables that may also include absolute value, integer exponents, square roots, pi, and/or scientific notation. **H.1A.4** Develop, identify, and/or justify equivalent algebraic expressions, equations, and inequalities using the properties of exponents, equality and inequality, as well as the commutative, associative, inverse, identity, and distributive properties. **H.3G.3** Apply a scale factor to determine similar two- and three- dimensional figures, are similar. Compare and compute their respective areas and volumes of similar figures. **H.3G.4** Apply slope, distance, and midpoint formulas to solve problems in a coordinate plane.	 **A.SSE** Write expressions in equivalent forms to solve problems. **A.CED** Create equations that describe numbers or relationships. **G.SRT** Understand similarity in terms of similarity transformations **G.GPE** Use coordinates to prove simple geometric theorems algebraically.

Roof Raising Students create model roof trusses and investigate basic trigonometry.	**H.1G.3** Apply theorems of corresponding parts of congruent and similar figures to determine missing sides and angles of polygons. **H.1G.4** Use trigonometric ratios (sine, cosine and tangent) and the Pythagorean Theorem to solve for unknown lengths in right triangles. **H.1G.5** Determine the missing dimensions, angles, or area of regular polygons, quadrilaterals, triangles, circles, composite shapes, and shaded regions. **H.2G.2** Identify and apply formulas for surface area and volume of spheres; right solids, including rectangular prisms and pyramids, cones; and cylinders; and compositions thereof. Solve related context-based problems. **H.3G.3** Apply a scale factor to determine similar two- and three- dimensional figures, are similar. Compare and computer their respective areas and volumes of similar figures.	**G.SRT** Prove theorems involving similarity. **G.SRT** Define trigonometric ratios and solve problems involving right triangles. **G.GMD** Explain volume formulas and use them to solve problems. **G.SRT** Understand similarity in terms of similarity transformations.
Electrical Students use batteries, bulbs, resistors, and multimeters to investigate the mathematical relationships in electrical circuits.	**H.1A.2** Evaluate, compute with, and determine equivalent numeric and algebraic expressions with real numbers and variables that may also include absolute value, integer exponents, square roots, pi, and/or scientific notation. **H.1A.3** Express square roots in equivalent radical form and their decimal approximations when appropriate.	**A.SSE** Write expressions in equivalent forms to solve problems. **N.RN** – Extend the properties of exponents to rational exponents.

	H.1A.4 Develop, identify, and/or justify equivalent algebraic expressions, equations, and inequalities using the properties of exponents, equality and inequality, as well as the commutative, associative, inverse, identity, and distributive properties. **H.2A.1** Identify, construct, extend, and analyze linear patterns and functional relationships that are expressed contextually, numerically, algebraically, graphically, in tables, or using geometric figures. **H.2A.5** Given a linear function, interpret and analyze the relationship between the independent and dependent variables. Solve for x given f(x) or solve for f(x) given x. **H.2A.8** Solve systems of two linear equations graphically and algebraically, and solve systems of two linear inequalities graphically.	**A.CED** – Create equations that describe numbers or relationships. **F.IF** Understand the concept of a function and use function notation. **A.REI** Represent and solve equations and inequalities graphically.
Energy Transfer Students use simple materials to investigate the mathematics of heat flow through different insulating materials. Graphing calculators or spreadsheets are introduced as tools for investigating linear equations.	**H.1A.1** Compare, order, and locate real numbers on a number line. **H.1A.2** Evaluate, compute with, and determine equivalent numeric and algebraic expressions with real numbers and variables that may also include absolute value, integer exponents, square roots, pi, and/or scientific notation. **H.2A.1** Identify, construct, extend, and	**A.SSE** Write expressions in equivalent forms to solve problems.

	analyze linear patterns and functional relationships that are expressed contextually, numerically, algebraically, graphically, in tables, or using geometric figures. **H.2A.2** Given a rule, context, two points, a table of values, a graph, or a linear equation in either slope intercept or standard form, identify the slope of the line, determine the x and/or y intercept(s), and interpret the measuring of each. **H.2A.3** Determine the equation of a line given any of the following information: two points on the line, its slope and one point on the line, or its graph. Also, determine an equation of a new line, parallel or perpendicular to a given line, through a given point. **H.1S.2** Evaluate data-based reports by considering the source of the data, the design of the study, and the way the data was analyzed and displayed. **H.1S.3** Compare and draw conclusions about two or more data sets using graphical displays or central tendencies and range. **H.1S.4** Use or construct a scatter plot for a given data set, determine whether there is a (n) linear, quadratic, exponential, or no trend. If linear, determine if there is a positive or negative correlation among the data; and, if appropriate, sketch a line of best fit, and use it	**A.CED** Create equations that describe numbers or relationships. **S.IC** Make inferences and justify conclusions from sample surveys, experiments, and observational studies. **S.ID** Summarize, represent, and interpret data on a single count or measurement variable. **S.ID** Interpret linear models. **S.ID** Interpret linear models.

	to make predictions. **H.1S.5** Construct analyze, and interpret tables, scatter plots, frequency distributions, and histograms of data sets.	
Architecture Students design and construct a simple model house to measure natural light levels under various conditions.	**H.1G.2** Apply theorems, properties, and definitions to determine, identify, and justify congruency or similarity of triangles and to classify quadrilaterals **H.1G.3** Apply theorems of corresponding parts of congruent and similar figures to determine missing sides and angles of polygons. **H.1G.4** Use trigonometric ratios (sine, cosine and tangent) and the Pythagorean Theorem to solve for unknown lengths in right triangles. **H.1G.5** Determine the missing dimensions, angles, or area of regular polygons, quadrilaterals, triangles, circles, composite shapes, and shaded regions. **H.3G.3** Apply a scale factor to determine similar two- and three- dimensional figures, are similar. Compare and compute their respective areas and volumes of similar figures.	**G.CO** Prove geometric theorems **G.CO** Prove geometric theorems **G.SRT** Prove theorems involving similarity **G.SRT** Apply trigonometry to general triangles. **G.SRT** Understand similarity in terms of similarity transformations.
Dog House Students use much of the geometry explored in other units to design and possibly construct a	**H.1G.5** Determine the missing dimensions, angles, or area of regular polygons, quadrilaterals, triangles, circles, composite	

dog house. The mathematics of the volume of solids is used to design a house that meets the needs of various types of dogs.	shapes, and shaded regions. **H.2G.1** Identify, classify, model, sketch, and label representations of three-dimensional objects from nets and from different perspectives. **H.2G.2** Identify and apply formulas for surface area and volume of spheres; right solids, including rectangular prisms and pyramids, cones; and cylinders; and compositions thereof. Solve related context-based problems. **H.2G.3** Identify and apply formulas to solve for the missing dimensions of spheres and right solids, including rectangular prisms and pyramids, cones, and cylinders, both numerically and symbolically. **H.3G.3** Apply a scale factor to determine similar two- and three- dimensional figures, are similar. Compare and computer their respective areas and volumes of similar figures.	 **G.CO** Prove geometric theorems **G.SRT** Understand similarity in terms of similarity transformations. **G.GMD** Visualize relationships between two-dimensional and three-dimensional objects.
Marketing Students use statistics and probability to develop a marketing plan for a product such as the dog house.	**H.1S.3** Compare and draw conclusions about two or more data sets using graphical displays or central tendencies and range. **H.1S.4** Use or construct a scatter plot for a given data set, determine whether there is a (n) linear, quadratic, exponential, or no trend. If linear, determine if there is a positive or	**S.ID** Summarize, represent, and interpret data on a single count or measurement variable. **S.ID** Interpret linear models.

	negative correlation among the data; and, if appropriate, sketch a line of best fit, and use it to make predictions. **H.2S.1** Identify, analyze, and use experimental and theoretical probability to estimate and calculate the probability of simple events. **H.2S.2** Determine the sample space of a probability experiment. **H.2S.3** Compute and interpret probabilities for independent, dependent, complementary, and compound events using various methods (e.g., diagrams, tables, area models, and counting techniques).	 **S.CP** Understand independence and conditional probability and use them to interpret data.

Relationship to the Common Core State Standards in Mathematics:
This project started prior to Oregon's adoption of the Common Core State Standards (CCSS). Possible links to the CCSS are listed in the table above and will be reviewed during the summer of 2012. In addition, the following math practices are reflected throughout the curriculum.

1. Make sense of problems and persevere in solving them.
2. Reason abstractly and quantitatively.
3. Construct viable arguments and critique the reasoning of others.
4. Model with mathematics.
5. Use appropriate tools strategically.
6. Attend to precision.

Appendix F

Analysis of Student Test Scores

In Year 2 of the Oregon Applied Academics Project, the state conducted student testing to measure performance trends during the development phase of the project. The primary objective was to determine if a positive treatment trend was observed in the Accuplacer performance of students enrolled in the newly developed technical mathematics course.

Results

In the three classrooms tested (*N* = 36 students), students' math skills increased, as indicated by their Accuplacer posttest scores. Average posttest scores for each of the three classrooms were significantly higher than pretest scores, suggesting that an average gain of 5 points per student can be attributed to the project (see Table 1).

Table 1
Descriptive Statistics and Paired-Samples t Test for the Pretest and Posttest Scores

	M	*N*	*SD*	*SE* Mean	*t*	*df*	Two-tailed *p*-value
Pretest scores	42.03	36	14.879	2.480			
Posttest scores	47.03	36	14.429	2.405			
Paired Differences							
Pretest - Posttest	-5.000		11.194	1.866	-2.680	35	.011

These results equate to an effect size of .34 (see Lipsey & Wilson, 2001, for a discussion of calculating effect sizes in one-group, pre-post designs). Effect sizes of this magnitude are considered to be in the small to medium range. These two statistics, taken in combination, suggest the intervention worked and had a medium effect on math achievement. This effect is comparable to those observed in class size reduction studies (e.g., Finn & Achilles, 1999).

Appendix G

Oregon Applied Academics Project
Year 3 Focus Group Questions

Together, you have undertaken the development and implementation of the technical math course. Thinking back, how would you describe the overall experience of participating in this project?

When you think about "the whole" of this project—the overall research and development process…

- What were the strengths or successes in R&D processes we used?
- What challenged you most in this R&D process?

Narrowing the focus a bit, what are your overall thoughts about the professional development sessions in which you participated over the past two years?

- What aspects of the PD sessions were particularly helpful or effective?
- What aspects of the PD should we be sure to retain for incoming teachers next year?
- What aspects of the PD should be improved for the incoming teachers next year?

What was the experience of partnering as math and CTE teachers?

- What can you tell us about your role?
- What worked? What didn't?
- What should we consider as we work with new teams in future professional development?

Focusing on the general implementation of the course… (this would include approvals, scheduling, enrollment, communications with parents, etc.)

- What were the barriers to implementation?
- What worked well or effectively to promote the implementation of the course?
- To what extent are you planning to implement the units next year and why?

What was the experience of teaching the technical math course?
(We will ask for specific feedback on the units later in the morning.)

What was it like to use a problem-based approach to teach math?

- What were the strengths of the approach?
- What challenged you?
- In what ways, if any, did your teaching change as a result of using this approach?
- In what ways, if any, did using this approach affect your perspectives about how students learn math?

How did your students respond to the course? What was the student experience?

- From your perspective, in what ways did the course and/or PBL approach benefit students' learning experiences?
- What were the challenges or issues for students who took the course? How did you resolve those issues? In this regard what needs to change next year?
- How do you think students' perspectives about math were affected by the PBL approach?
- Would you share a story that illustrates the student experience?

Overall, what would you recommend as the model is shared with others in the future?

Final comments? Is there anything we neglected to ask that you would like to add or comment on?

Appendix H

Oregon Applied Academics
Student Interview Questions
Spring 2012

10-15 minute interviews

Interviewer introduces herself. Explain that researchers are developing a different kind of math class and would like to have students' input.

"I would like to ask you some questions about your experience in your math class this year. We are not asking about your teacher, but about what you learned and did. We would like you to tell us about both good and bad things—your answers will not be shared with your teacher or your principal. This will not affect your grade. We will include your answers with other students' without using personal names or school names."

> What was it like to learn math in this class?
> How would you describe this class to a friend?
>
> What kinds of activities did you do?
> What did you find hard to do?
> What did you like about the activities? What was favorite activity and why?
>
> Has this class changed how you feel about math? How so? Tell me a little about that.
>
> Many kids will ask the question, "How will I use this math anyway?" How would you answer this question?
>
> Do you have anything else you would like to share about your experience in the class?

Select sample:

Contact school to get their permissions
Teachers ask for volunteers
Teachers select from five volunteers to interview from a mix of boys and girls who:

- Excel in math or in course
- Struggle with math or course
- Turn-around stories or articulate students
- Have CTE background
- Non-CTE

Appendix I

Regression Coefficients for Hypothesized Full LGM – Math Achievement

Predictors	Full LGM 1 Intercept *b*	*SE*	β	Full LGM 1 Slope *b*	*SE*	β	Full LGM 2 Intercept *b*	*SE*	β	Full LGM 2 Slope *b*	*SE*	β	*Accup1 *b*
Tech Classroom	-	-	-	-1.46	.98	-.04	-	-	-	-	-	-	-
Geo Classroom	-	-	-	-	-	-	-	-	-	-1.10	2.08	-.02	-.36
Alg Classroom	-	-	-	-	-	-	-	-	-	3.12	.68	.07	-
Class Mean Math Achieve	-	-	-	.57	.18	.17	-	-	-	.51	.14	.15	-
Teacher 2	.83	1.29	.02	3.49	2.44	.07	.86	1.26	.02	3.36	2.37	.07	-
Teacher 3	.16	1.62	.00	3.51	1.59	.06	.13	1.53	.00	3.70	1.43	.06	-
Teacher 4	-1.37	1.40	-.03	5.41	1.68	.08	-1.09	1.77	-.02	3.21	1.66	.05	-
Teacher 5	-3.57	1.94	-.11	7.95	2.25	.20	-3.26	1.55	-.10	5.71	1.82	.14	-
Sex	2.90	1.97	.09	1.26	1.63	.03	2.90	2.00	.09	1.20	1.59	.03	
Hispanic	-.23	2.60	.00	-5.25	3.11	-.06	-.20	2.58	.00	-5.51	2.99	.07	-
Am Indian	-6.28	3.68	-.08	9.72	2.74	.10	-6.25	3.69	-.08	9.54	2.73	.10	-
Asian	-6.32	1.02	-.05	-21.54	2.52	-.14	-6.22	1.18	-.05	-22.29	2.52	-.14	-
Black	-1.20	5.56	-.01	.50	6.50	.00	-1.19	5.53	-.01	.311	6.61	.00	-
Hawaiian	-17.87	3.26	-.07	-25.83	5.98	-.07	-17.9	3.24	-.07	-25.62	5.79	-.07	-
Grade Level	-.11	.19	-.03	.99	.17	.21	-.10	.19	-.03	.94	.18	.20	-
Age	2.26	1.53	.13	-3.80	2.19	-.17	2.30	1.66	.13	-4.21	2.38	-.18	-
Average Grade	.76	.99	.07	1.87	1.98	.14	.77	1.01	.08	1.76	2.03	.13	-
School Plans	1.86	.55	.21	1.23	.68	.11	1.86	.55	.21	1.24	.67	.11	-
Work Hours	-1.15	.56	-.17	.32	.37	.04	-1.15	.56	-.17	.27	.38	.03	-
Math Cred Taken	-.37	.45	-.03	-.80	.60	-.06	-.37	.46	-.03	-.74	.62	-.05	-
CTE Cred Taken	1.86	1.05	.06	.06	2.02	.00	1.82	1.09	.06	.29	.29	.01	-

Note. Grayed areas mark statistically significant effects at $p < .05$.

Appendix J

Regression Coefficients for Hypothesized Full LGM – Math Attitudes

	Full LGM 1						Full LGM 2						Interactions
Predictors	Intercept			Slope			Intercept			Slope			*Accup1
	b	*SE*	β	*b*	*SE*	β	*b*	*SE*	β	*b*	*SE*	β	*b*
Tech Classroom	-	-	-	.16	.08	.10							-
Geo Classroom	-	-	-	-	-	-	-	-	-	-.01	.14	-.01	-.01
Alg Classroom	-	-	-	-	-	-	-	-	-	-.25	.08	-.14	-.01
Class Mean Math Achieve	-	-	-	.01	.01	.08	-	-	-	.01	.00	.10	-
Teacher 2	-.20	.13	-.08	-.15	.12	-.08	-.20	.15	-.08	-.14	.09	-.07	-
Teacher 3	-1.02	.10	-.35	-.14	.16	-.06	-1.01	.13	-.35	-.15	.12	-.06	-
Teacher 4	-.33	.21	-.10	.07	.15	.03	-.44	.22	-.13	.20	.12	.07	-
Teacher 5	-.25	.12	-.12	-.13	.13	-.08	-.35	.19	-.18	.00	.10	.00	-
Sex	.54	.13	.27	.27	.10	.17	.54	.13	.27	.27	.10	.17	-
Hispanic	.19	.10	.05	-.12	.21	-.04	.18	.11	.04	-.10	.21	-.03	-
Am Indian	.11	.21	.02	-.16	.19	-.04	.10	.21	.02	-.25	.19	-.04	-
Asian	-.09	.56	-.01	.27	.07	.04	-.13	.53	-.02	.31	.07	.05	-
Black	-.25	.35	-.03	.43	.24	.08	-.26	.35	-.04	.44	.24	.08	-
Hawaiian	-1.53	.18	-.09	1.93	.18	.14	-1.52	.18	-.09	1.91	.18	.14	-
Grade Level	.02	.01	.07	-.01	.01	-.03	.01	.02	.05	.00	.01	-.01	-
Age	.28	.06	.25	.06	.07	.06	.26	.06	.23	.08	.07	.09	-
Average Grade	.04	.05	.06	-.02	.02	-.04	.04	.05	.06	-.02	.02	-.03	-
School Plans	-.12	.04	-.21	-.02	.03	-.04	-.12	.04	-.21	-.02	.03	-.04	-
Work Hours	.10	.02	.22	-.06	.02	-.18	.09	.02	.22	-.06	.02	-.17	-
Math Cred Taken	-.09	.05	-.13	.10	.03	.19	-.09	.05	-.13	.10	.03	.17	-
CTE Cred Taken	.13	.12	.06	.04	.10	.03	.13	.12	.06	.03	.09	.02	-

Note. Grayed areas mark statistically significant effects at $p < .05$.

Appendix K

Covariances and Correlations for Hypothesized Full LGM 2

	1	2	3	4	5	6	7
1. Geo Classroom	1						
2. Alg Classroom	-.07(.06) [-.36]	1					
3. Class Math Achieve	-.15(.85) [.06]	.98(.80) [.37]	1				
4. Math Ach Intercept	.06(.94) [.01]	.77(.53) [.12]	27.40(7.76) [-.16]	1			
5. Math Ach Slope	-	-	-	-	1		
6. Math Attitudes Intercept	.03(.04) [.09]	.04(.03) [.12]	-.83(.71) [-.16]	-4.08(1.06) [-.32]	-	1	
7. Math Attitudes Slope	-	-	-	-	.20(.70) [.02]	-	1

Note. Grayed areas mark statistically significant effects at $p < .05$.

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