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Integrating STEM and Literacy through Engineering Design: Evaluation of Professional Development for Middle School Math and Science Teachers (Program/Curriculum Evaluation)

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Mike Carte attended West Virginia State College from 1990-1994 where he majored in chemistry and minored in biology. He graduated magna cum laude with a Bachelor of Science degree. While a student at State, Mr. Carte played baseball for the Yellow Jackets, and was named an NAIA All-America Scholar-Athlete in 1993. During the summer preceding his senior year, Mr. Carte was admitted into the inaugural class of the Governor's Internship Program and served at the West Virginia Office of Air Quality. Upon graduation in May 1994, Mr. Carte took a position as an environmental chemist with the West Virginia Department of Environmental Protection. After two years as a chemist, he enrolled in graduate school at Marshall University, where he obtained a Master of Arts in Teaching degree in December 1996.

After a two month, long-term substitute position at DuPont Junior High School (Belle, WV) in the spring of 1997, Mr. Carte began teaching full-time in August 1997 at South Charleston High School. During his eight-year tenure, Mr. Carte taught general science, International Baccalaureate chemistry, and physics. He also served as the academic coach. Mr. Carte moved to Riverside High School (Belle, WV) in August 2005 and undertook the challenge of starting an Advanced Placement chemistry program. Following the implementation of an AP program and a seven-year stint at Riverside, Mr. Carte took a chemistry position in August 2012 at George Washington High School in Charleston, West Virginia.

Mr. Carte has received several professional honors and service opportunities during his career. He was named to Who's Who Among American Teachers in 2001 and 2005. Moreover, during the 2003-2004 school year, Mr. Carte served as President of the West Virginia Academic Coaches Association. He was recognized as an outstanding teacher by the West Virginia Governor's Honors Academy in 2006 and 2008, and in 2005, he served on West Virginia Instructional Materials Selection Committee for Science. He served on the WESTEST II Item Writing Committee for Chemistry in 2009. While at Riverside High School, Mr. Carte was named Kanawha County Teacher-of-the-Year in 2010.

In 2012, Mr. Carte gained certification from The Princeton Review to be a part-time general chemistry instructor, and has taught preparation courses for the Medical College Admissions Test at Marshall University. For the past two years, he served as the College and Career Ready/STEM Coordinator for Regional Education Service Agency (RESA) 3 where he provided services to Kanawha, Putnam, Boone, and Clay counties in the areas of instructional practices, staff development, grant writing, and STEM activities.

As part of his duties at RESA 3, Mr. Carte became a certified Literacy Design Collaborative trainer by the Southern Regional Education Board. He was one of five trainers that helped initiate Cohort I in West Virginia at High Schools That Work locations. He completed SREB's LDC Trainers Academy during the summer of 2014, and was often called upon to work with schools and districts in the area of literacy.

Mr. Carte is the former director of Project TESAL (Teachers Engaged in STEM and Literacy), which is a three-year, federal Math-Science Partnership Grant award designed to provide professional development to middle school teachers within RESA 3 in the areas of engineering design and literacy. Additionally, Mr. Carte is overseeing the writing of SREB's Middle School STEM Curriculum, which should be completed during the summer of 2016.

Mr. Carte has been married to the former Caroline Ramella for 16 years and they have two sons, Aaron and Jonah, ages 13 and 9 respectively. He currently resides in Charleston and serves as a chemistry instructor at George Washington High School.

Integrating STEM and Literacy through Engineering Design: Evaluation of Professional Development for Middle School Math and Science Teachers

Abstract

We describe a professional development program that supports integration of STEM and Literacy through Engineering Design for 24 in-service middle school math and science teachers in rural Appalachia. Through this program, teachers experience Engineering Design as learners, develop lesson plans utilizing engineering design to teach specific relevant math and science content standards and objectives, and receive formative feedback and content knowledge coaching as they deliver and fine-tune those lessons.

Project TESAL (Teachers Engaged in STEM and Literacy) is a three-year professional development program that includes annual two-week summer face-to-face intensive workshops followed by classroom observations with supportive feedback and four additional day-long trainings throughout the school year. We describe the program in detail, as well as evaluation findings from the first year of implementation.

Project TESAL has been successful recruiting a diverse group of mathematics, science, and special educators, and at engaging them in professional development they find valuable. The T-STEM survey revealed that professional development successfully increased participating teachers' confidence to teach engineering design, their confidence that they can influence their students' STEM performance, and their knowledge of STEM careers, as well as the amount they expect to utilize technology and instruction following STEM best educational practices.

Participating teachers identified several strengths of Project TESAL. Participants particularly valued being active participants in learning, opportunities for collaborating with peers and outside experts around the work of teaching, focusing on subject matter content across mathematics and science and students' learning of that content, and the sustained ongoing nature of Project TESAL where the work teachers did in professional development was fully relevant to their work as classroom teachers. These strengths align directly with best practices for professional development and for overcoming the challenges of professional development specifically on math-science integration and engineering design instruction.

Introduction

Rising Above the Gathering Storm [1] identified the need to "encourage more US citizens to pursue careers in mathematics, science, and engineering." In West Virginia, only 17% of adults over 25 have a Bachelor's degree, the lowest rate of any state, and many communities have much lower rates [2]. To improve the economic competitiveness of our region and to contribute to national prosperity, we must encourage and prepare students to contribute to the high-tech economy. Workforce West Virginia projects a growth in all STEM jobs in the state from 2010-2020, with over 2,000 health care and 700 non-health care job openings annually. Yet, by almost any measure, the difficulties in attracting high school students to STEM careers are enhanced in Appalachia, and especially in West Virginia [3-4]. Declining population with out-migration of college graduates and in-migration of less-than-high-school graduates characterizes this region. Given that many Appalachians desire to live, work, and make a difference in their home communities [5], the *vision* underlying this project is to leverage engineering design of appropriate technologies applicable to societal challenges in both developing nations and resource-poor rural areas. Doing so will be a powerful context for teaching and learning, and for motivating and preparing students in West Virginia to pursue STEM educational and career paths that enable them to contribute to their home community.

Many West Virginia schools are small with significant weaknesses in science and mathematics teaching. The Economic Research Service classifies counties as low education counties if "25 percent or more of residents 25-64 years old had neither a high school diploma nor GED." In West Virginia, 13 of 55 counties are classified as low education counties [6]. In addition, students in West Virginia score well below national means on mathematics and science achievement tests. Many West Virginia students are not well prepared in mathematics and science and only a small percentage elect to study in STEM fields. As a result, West Virginia awards a significantly lower percentage of degrees in STEM related fields (21%) than the national average (30%).

We build on existing approaches to eliminate gaps between classroom math/science and real world problem solving in science and math [7]. These approaches include developing special skills of modeling more abstract concepts and utilizing a greater number of hand-on activities in the classroom [8]. These approaches benefit all students including those in lower achieving brackets [9]. The benefits of folding authentic contexts into classroom tasks provide an opportunity for greater engagement of students in their own understanding of realistic situations [10] as well as developing their own scientific reasoning for those situations [11]. Within engineering design based approaches, problems presented to students as contexts for teaching concepts are ill-defined and do not require a specific order of steps to be followed [11]; this in contrast to more traditional methods that necessitate student responses in terms of a single correct solution. One useful definition of design is, "Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints" [12]. Once the design process is mastered students are able to: a) tolerate ambiguity and cycle from divergent to convergent thinking processes in an iterative loop to find a design solution, b) maintain sight of the big picture, c) handle uncertainty, d) justify and make decisions, e) think as part of a team in social processes, and f) think and communicate in several languages of design [12]. Further, these new types of solutions often relate to real problems in our environment that require manual manipulation of physical elements and materials [13]. Such a manipulation gives an opportunity to expose students to authentic problems and guide them through their experience to improved content knowledge [14].

Another important advantage offered by modeling activities is closely connected to students designing their own artifacts [11], and thus further improving their ability to manipulate and navigate changing circumstances and perspectives including actively taking ideas apart and putting them back together based on data driven speculation [7]. Students are actively involved as they create explanations, make predictions, and argue their positions based on evidence they collect [14]. These new student proficiencies go beyond low-level skills that are fostered in test-driven curricula and expand to multi-leveled solutions and organized collections of facts and relations among concepts [7, 13].

Our engineering design based approach to teaching content and developing problem solving skill dictates a new role for the teacher as well. Teachers must shift from an evaluative perspective to an interpretive one as they move away from guiding students to correct answers and toward emphasizing student exploration and engagement [15]. The teachers' focus should target encouragement of students' own reflections on their reasoning and interpretations of problem situations [7]. Contrary to current practices of warning students when they take a wrong step in their solution efforts, teachers need to encourage students to focus on their interpretation specific ideas and their connections to the problem at hand [13].

Project TESAL ("Teachers Engaged in STEM And Literacy") targets development of these new roles in teachers' practice as well as improved understanding of mathematical and science content for middle school as integrated in an engineering design based method [15]. Project TESAL professional development incorporates the promotion of interdisciplinary knowledge across the areas of science, math, and engineering. We strive to shift students and teachers from being processors of information toward becoming creators of mathematics and science models [7] as tools to solve societally relevant scientific challenges through the design and development of appropriate technologies, which are small scale technologies that are simple enough that they can be managed locally to improve the lives of a community.

Common core middle school education standards include design as a component of engineering in the science framework, but the design process is not always easy to learn. Teacher preparation and scaffolding support are key to successful implementation of engineering design based learning and have been shown to lead to significant gains in the classroom [16]. Consistent with research literature on improving mathematics and science education, Project TESAL addresses both teachers' knowledge of content and their knowledge of pedagogy [17]. Teachers need a deep understanding of the mathematics and science they will teach. They also need knowledge of how students develop understanding of content, how to set significant learning goals, how to select and implement appropriate instructional methods, and how to assess whether those goals are met [18]. Well-designed professional development experiences are integral to developing such knowledge and skills [19].

Features widely discussed in the literature as characteristics of quality professional development include: experiences that are ongoing and sustained, experiences that encourage teachers to be active participants in learning, experiences that provide opportunities for collaborating with peers and outside experts around the work of teaching, experiences that focus on subject matter content and students' learning of that content, and experiences that align with other school improvement efforts [19-23]. Professional development experiences aligned with these recommendations have resulted in positive impacts on teachers' knowledge of content, instructional practice, and beliefs about mathematics and science teaching and learning [24]. One common element in many of the recommended best practices for professional development in mathematics and science is engaging teachers with significant mathematics and science content that is embedded in experiences coherent with the work of teaching. An example of this type of professional development is teacher or practitioner research, in which teachers engage in systematic study of their instruction and the resulting student learning outcomes [25]. Engaging in this cycle of inquiry provides opportunities for teachers to learn from their own practice and the practice of others [26]. The teachers in Project TESAL are integrally involved in developing curriculum modules, delivering those modules, and assessing their impact through iterative design and development cycles.

Project TESAL Guiding Principles/Orientation

Project TESAL incorporates the characteristics of effective professional development in mathematics and science. Teachers engage in significant mathematics and science content related to the work of teaching as they participate in developing, designing, implementing, and refining modules that address content standards and objectives in middle school mathematics, science, and engineering design. Further, teachers collaborate with peers and experts in engineering design, science, and mathematics education as part of a team inquiring into the impact of their instruction on their students. Participating teachers working with and supported by their team move through learning, development, and implementation cycles. This work is aligned with research in that is ongoing, content-focused, embedded in the work of teaching, and aligned with the implementation of the WV State Standards.

National standards documents have made clear that mathematics is an essential tool for making scientific inquiry, and science is a context for developing mathematics competence (e.g., measurement, data analysis) [27-28]. The potential to mutually reinforce science and mathematics understandings while teaching either discipline is one of the most pragmatic and readily available interdisciplinary opportunities for all learners [29-30]. The *Common Core State Standards for Mathematics* [31] and *A Framework for Science Education* [32] reinforce and expand these opportunities. The *Framework* gives engineering and technology a greater focus. *CSSM* content domains such as measurement and data, and modeling, and standards for mathematical practice such as persevering in problems, making sense of mathematical problems, and choosing appropriate tools integrate well in our approach with science and engineering practices from the next generation standards such as “asking questions and defining problems” and “using mathematics and computational thinking”, as well as crosscutting concepts focused on “systems and system models”[36]. Engineering design projects of appropriate technologies provide extensive opportunities for engaging in practices that are common to both the *CSSM* and *Framework*: defining problems, constructing explanations, developing models, and attending to precision. Importantly, our approach provides rich opportunities for engineering design and to link engineering technology, science, and society: core ideas within dimensions of the *Framework.*

Program design and implementation

Project TESAL is a three year program consisting of two weeks of instruction during the summer each year followed by two one day workshops per semester together with classroom support and observations. The three years are themed around one aspect of the middle school science curriculum (Year 1: Physical Science; Year 2: Life Science; and Year 3: Earth Science) with interwoven math content and literacy. The literacy component also follows a three year progression with the Focus of Year 1 on Argumentation; Year 2 on Informational; and Year 3 on Narrative. Participating teachers remain in the program all three years. The program design is summarized in Figure 1.

Figure 1: Project TESAL Program Design and Participating Teachers Building Roller Coaster

Project TESAL is a Math Science Partnership with a collaborative team consisting of the director of the Regional Education Service Agency (RESA) serving the relevant counties, a middle school chemistry teacher with expertise in science and literacy serving as coordinator of Project TESAL for the RESA, university faculty specializing in curriculum resources, mathematics education, mechanical engineering, materials science, and educational research/evaluation, and two doctoral students in education.

Initial planning began January 2015, including finalization of project roles for implementation, outline and planning for professional development, and finalization of evaluation design. Participating teachers were recruited through the RESA. June 2015 participating teachers were assigned to project teams for upcoming professional development sessions. To construct the teams, teachers were kept together with other teachers from their school and each group had at least one math teacher, at least one science teacher, and at least one experienced teacher with a record of teaching excellence. Group names were chosen using a fruit theme – grapefruit, tangerine, lime, orange, and lemon.

An example project was woven through the two weeks of summer training to design a roller coaster. This allowed participating teacher to experience an engineering design based lesson as learners. The roller coaster was first assigned as a project to build a paper roller coaster that would take a specific time for a marble to traverse the track. The roller coaster was used to introduce the Design Process (see Figure 2) and the importance of redesign. The redesign process was used as an example literacy assignment with participants writing an instruction manual on how to build their redesigned roller coaster. Once they had completed the redesign we had groups provide their instruction manual to a different group who then had to build a roller coaster from just the instructions provided. Participating teachers were required to complete at least two lesson plans, and to implement at least one of those lessons during fall 2015. A detailed agenda for the summer session and one fall follow-up session is provided in the Appendix.

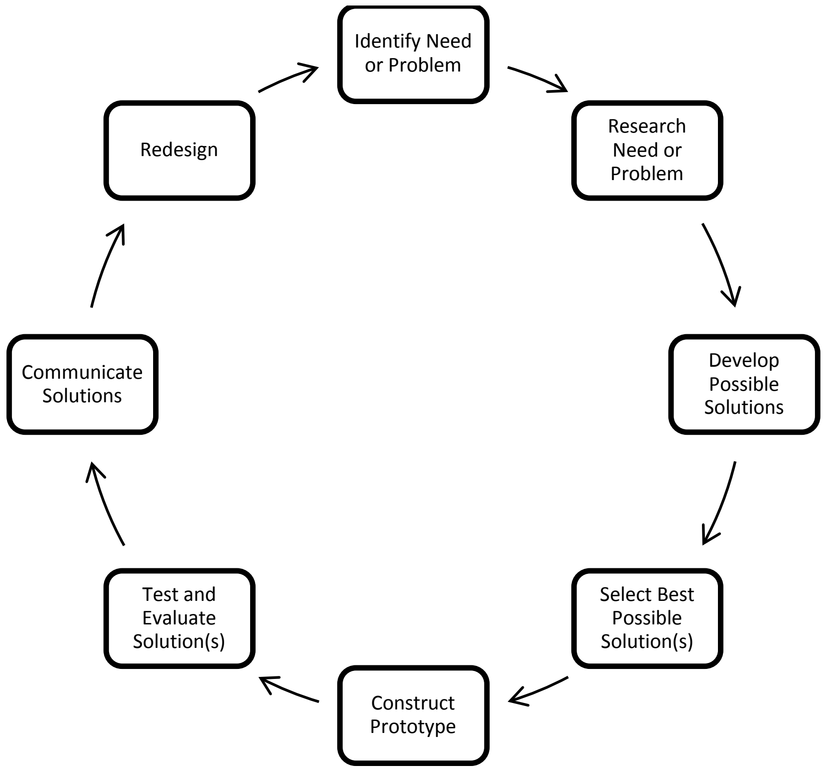


Figure 2: Design Process Model Utilized with Participating Teachers

Program Evaluation

The evaluation of Project TESAL is guided by participatory program evaluation theory, which actively involves program stakeholders in evaluation efforts as stakeholders bring essential expertise and perspective on program functioning and are in a position to utilize evaluation findings for decision making and program improvement [33]. Evaluation and implementation personnel collaborate to conduct program evaluation serving three overarching purposes: a) to document evidence of specific implementation and program impacts on teacher level outcomes (e.g. content knowledge and pedagogical skills), b) to document evidence of specific implementation and program impacts on student level outcomes (e.g., student state assessment achievement), and c) to provide support for continuous program improvement in implementation and effectiveness relative to student and teacher level outcomes.

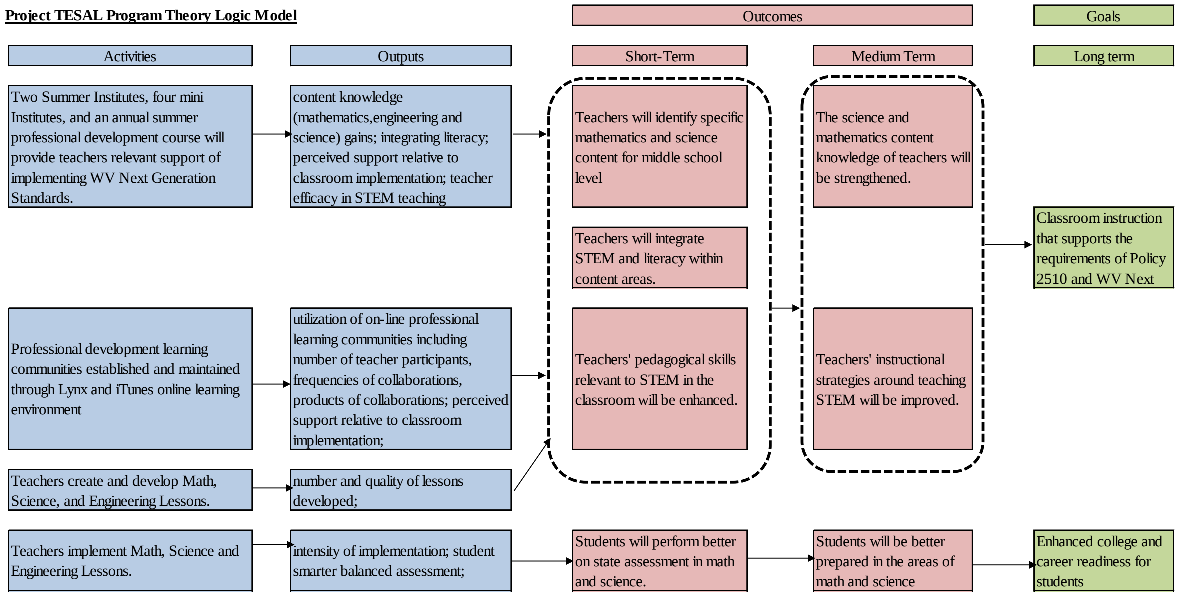


Figure 3: Project TESAL Program Theory Logic Model

Project TESAL evaluation utilizes program theory logic modeling. The logic model developed for Project TESAL informs appropriate metrics to track program activities, outputs, and progress toward short, medium and long term objectives (see Figure 3). Tracking, analysis, and evaluation of these metrics are shared collaboratively with all Project TESAL stakeholders to inform continuous improvement of specific implementation strategies, as well as to document impact on outcomes and objectives. The pervasive long-term evaluation question is, "*What impact does Project TESAL have on developing teachers' STEM-related content knowledge, pedagogical skills, and on students' academic achievement in science, mathematics, and English language arts/literacy?"* Key data sources and timelines for data collection are summarized in Table 1.

Project TESAL interventions aim at more prepared, confident, and effective STEM teachers to support greater student academic achievement and career aspiration in STEM related fields. Students are tracked across the duration of the project and performance and completion data collected from WV Department of Education housed data (e.g., Smarter Balanced assessments). Students who are in TESAL teachers' classrooms will be matched with non-TESAL teachers' students. The students will be matched through propensity scores calculated based on student academic characteristics (e.g., baseline state assessment scores, GPA, subgroup membership). When analyzing the effect of TESAL on student achievement scores, baseline data will be used to control for past performance. While we will utilize this quasi-experimental design with propensity score matching to examine longitudinal impact across time in later years, that data is not yet available.

Table 1: Evaluation activities, data sources, and timeframes

Evaluation Activities	Description/Data Source	Timeframe
Evaluation of professional development impact on teachers, including teacher content knowledge and pedagogical skill	Teacher Report Satisfaction and Perceived Support Teacher Efficacy in STEM teaching; DTAMS Mathematics and Science Observation of application of TESAL training in implemented lessons	Posttest fall 2015, 2016, and 2017 Pretest summer 2015, then posttest spring 2016, 2017, and 2018 Fall 2015, 2016, 2017
Evaluation of Impact on Student Achievement	State-mandated standardized assessment (Smarter Balanced), Student characteristics, and Implementation intensity	Baseline from previous 3 years, Spring 2016, 2017, and 2018

At this point in the implementation of the project, we focus on impact of year 1 professional development on participating teachers. This paper focuses on analysis of surveys completed prior to and after professional development, content knowledge tests completed prior to professional development, focus group discussions conducted near the end of the summer professional development sessions, post-professional development surveys, teacher-generated engineering design lesson plans, and observations of participating teachers as they implemented engineering design lessons in their classrooms.

Participants

Project TESAL works with teachers from four mostly rural counties in WV that face common challenges according to 2012-2013 mandated reporting educational metrics. These counties range from 41% to 67% low-income students, over half have less than 80% highly qualified teachers in mathematics or science, and all schools in these counties have mathematics and science standardized achievement test scores below the WV state average in a state that is well below the national average. Five of the middle schools in these counties are designated “focus schools” because of identified mathematics or reading achievement gaps in special education and low-SES subgroups.

All participating teachers completed a project application including demographic information. There were 24 participating teachers with 1 to 32 years teaching experience (median = 8 years). These teachers considered themselves primarily science educators (n=11), mathematics educators (n=8), special educators teaching math or science (n=4) or technology educators teaching math or science (n=1). Of the 24 participating teacher, all had at least a bachelor degree and 17 (70%) were highly qualified based on the federal definition requiring at least a bachelor degree and being fully certified/licensed in their academic subject area.

Evaluation findings- Surveys

The Teacher Efficacy and Attitudes toward STEM (T-STEM) survey was administered at the outset of the first face-to-face professional development session and immediately following the final professional development session for summer 2015. This measure has strong validity and reliability, including Cronbach's alpha coefficients ranging from .81 - .95 across subscales with science and mathematics teachers [34]. T-STEM measures 7 subscales utilizing 62 Likert-type items (5-point). Negatively worded items were reverse coded so that higher numbers indicated stronger positivity or greater frequency.

Subscale names and representative item text are provided in Table 2. Table 3 presents pre and post-professional development subscale means as well as results of dependent samples t-tests assessing change across time. Dependent samples t-tests ($p<.05$) revealed significant increases in Engineering Design Teaching Efficacy/Beliefs, STEM Teaching Outcome Expectancy, Student Technology Use, STEM Instruction, and STEM Career Awareness. While significant change was not found for 21st Century Learning and Teacher Leadership Attitudes, participating teachers rated these very highly prior to the professional development sessions with means near 4.5 on a 5-point scale.

A professional development evaluation survey was administered at the end of the summer sessions. Average ratings of the facility and food, quality of instructors, and clarity and usefulness of content covered were all 4.0 or higher with most averages above 4.5 on a 5 point scale. Likelihood of recommending and returning to the workshop were both greater than 4.9 on a 5 point scale. The following is a common example of open-ended responses on this survey:

> *I think that this was an extremely productive workshop and I can honestly say that I have learned more from this ten days than any other professional developments that I have attended (based on a lot of PD's). I also enjoyed the fact that all of the instructors were extremely knowledgeable and were able to give so many tips, share examples, and life experiences that directly related to the workshop. I think that this workshop is a great way to learn how to incorporate science, math, engineering, and literacy into future lessons.*

--Project TESAL Participating Teacher

Table 2: T- STEM subscales and representative items

Subscale	Sample Item
Eng. Design Teaching Efficacy/Beliefs (11 items)	I know the steps necessary to teach engineering design effectively.
STEM Outcome Expectancy (9 items)	When a student does better than usual in STEM, it is often because the teacher exerted a little extra effort.
Student Technology Use (8 items)	During STEM instructional meetings (e.g. science class, mathematics class, STEM-related clubs or organizations, etc.), how often do your students…Use a variety of technologies, e.g. productivity, data visualization, research, and communication tools.
STEM Instruction (14 items)	During STEM instructional meetings (e.g. science class, mathematics class, STEM-related clubs or organizations, etc.), how often do your students…Develop problem-solving skills through investigations (e.g. scientific, design or theoretical investigations).
21st Century Learning (11 items)	I think it is important that students have learning opportunities to…Lead others to accomplish a goal.
Teacher Leadership Attitudes (6 items)	I think it is important that teachers …Take responsibility for all students' learning.
STEM Career Awareness (4 items)	I know…About current STEM careers.

Table 3: T- STEM pre-post means, standard deviations (SD) and paired samples t-test results.

N=22	Pre-PD Mean (SD)	Post PD Mean (SD)	t	df	Sig. (2-tailed)
Eng. Design Teaching Efficacy/Beliefs	2.86 (.67)	3.86 (.41)	7.73	21	0.00
STEM Teaching Outcome Expectancy	3.41 (.41)	3.54 (.55)	1.49	21	0.15
Student Technology Use	2.72 (.60)	3.09 (.91)	2.19	21	0.04
STEM Instruction	2.99 (.59)	3.41 (.64)	3.19	21	0.00
21st Century Learning Attitudes	4.58 (.36)	4.48 (.45)	-0.92	21	0.37
Teacher Leadership Attitudes	4.53 (.37)	4.67 (.37)	1.29	21	0.21
STEM Career Awareness	3.38 (.78)	4.32 (.11)	6.05	21	0.00

Evaluation findings- Mathematics and Science Content

Diagnostic Teacher Assessments in Mathematics and Science (DTAMS) for middle school were utilized. DTAMS has demonstrated strong reliability and validity for middle school teachers across multiple examinations [35]. DTAMS-mathematics was created by combining DTAMS items from various subtests (i.e., Algebraic Ideas, Geometry and Measurement, Number and Computation, Probability-Statistics) specifically relevant for WV content standards and objectives upon which WV middle school students most often struggle. Year 1 DTAMS- science was the full DTAMS Physical Science assessment for middle school.

DTAMS mathematics and science assessments are majority multiple-choice items with 4 or 6 open-ended items, respectively, and a total possible score of 22 for each assessment. Open-ended items were scored based on content accuracy for this analysis. As shown in Table 4, participating teachers did poorly outside of their content area focus, scoring 50-60% on average. Science teachers outperformed their peers on the science assessment (74% correct on average) and mathematics teachers outperformed their peers on the mathematics assessment (80% correct on average). Non-parametric Kruskal-Wallis analyses (due to small sample size) confirmed the statistical significance ($p<.05$) of differences across content area teacher groups.

Table 4: Science and mathematics content knowledge means (standard deviations).

	DTAMS Science Content Score	DTAMS Math Content Score
Science Teachers n=11	16.18 (4.24)	13.09 (3.73)
Mathematics Teachers n=8	11.38 (3.96)	17.50 (2.88)
Special Education and Technology Teachers n=5	11.20 (4.94)	12.20 (3.70)
Total N=24	13.54 (4.72)	14.38 (4.02)

Closer inspection of the items on the mathematics assessment reveals that items for which an incorrect response was given more than 60% of the time were distributed across mathematics topics and domains, including data analysis, expressions and equations, and rational number and proportional reasoning. Analyses of these items suggests that, rather than the particular mathematical topic, it was the nature of these questions that may have created more challenge. While other questions having higher correct response rates were more routine in nature, requiring teachers to apply an algorithm or formula, the questions that had higher rates of incorrect answers required more analysis, reasoning, and application. Thus, these questions required understanding beyond simple procedural knowledge of the mathematics.

Closer inspection of the items on the science assessment revealed two areas of weakness described here in the context of Next Generation Science Standards[36]:

1) Real World Newtonian Physics (*MS-PS2-2= Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.*) In particular one half of the teachers were not able to correctly identify the relative motion of an object dropped from a plane or articulate how to consider friction forces.
2) Thermal Transport by Convection (*MS-PS3-3= Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.*) In particular only 7/24 teachers correctly identified that wall insulation traps pockets of air that prevent heat to flow by convection.

During the summer we targeted these areas of weakness through the roller coaster design project as a concrete example of real world Newtonian Physics and a design project to manufacture a lunch box to keep food warm, as well as multiple applications of mathematical thinking to solve engineering design challenges.

Evaluation findings- Focus groups

During focus group interviews, the teachers were asked, "How has this professional development impacted you?" Their responses suggested positive impact that in some cases exceeded their expectations. Participating teachers spoke of how the professional development facilitated reflection and rethinking of their practice in the classroom. For example, one participant stated, "*This is good for me, it has made to try to think about the lessons that I do give my students and made me try and incorporate a little more hands on activities*."

Participating teachers also addressed how the professional development aided in "*expanding their horizons*" and "*overcoming inhibitions about integrating math into science*". They described the potential of integrating Math and Science in their classroom as suggested by these responses.

> *It has opened up a whole new world of integrating math and science. I have done my projects in my room before but integration of the two content areas would really benefit the kids, [and] that is what we are here for. So I think learning from the science teachers is awesome. Lots of opportunity. ---Project TESAL Participating Math Teacher*

> *I would say that it really enhanced my practice because I get a greater understanding of grading math and science with everything I do… like all the different activities but not just projects for science learning but also to combine those together so the kids understand it deeper. ---Project TESAL Participating Science Teacher*

However, when asked, "How do you expect what you learn in this professional development to impact your work as a teacher this coming year?", some teachers expressed concerns about the lack of resources such as limited lab space in their school and availability of supplies as a hindrance to them using what they learned at the professional development.

Others addressed concerns around planning their lessons to ensure that the content standards and objectives were integrated well, as well as general time management concerns as noted by one participant's responses.

> *I think just by incorporating more guided inquiry lessons it would probably save time on the back end. When you are not doing those sorts of lessons, you end up having to reteach some of [the] kids who did not pick it up the first time. So I mean I think it should hopefully save time and help us move a little faster. ---Project TESAL Participating Teacher*

The teachers also emphasized the value that they gained by familiarizing themselves with standards across disciplines as a step toward greater integration across content areas. One participant noted:

> *I think science teachers get science standards, math teachers look at math standards, and I think that was one of the reasons I was so skeptical about putting lots of math in my*

science lessons because I did not know what they [students] should already know. And I was always so scared to go above their head and I realized that that is what they should already be doing and knowing. ---Project TESAL Participating Science Teacher

The teachers also shared their excitement about trying the lessons that they created during the professional development, collaborating with teachers in their schools, and helping students make connections across disciplines.

We do it as teachers; that is the way that we learn. Now we have to help construct those connections for our students. The importance of collaboration for students, like we are collaborating now. We learn so much from each other, how much more so will students learn from each other in the classroom. ---Project TESAL Participating Teacher

Evaluation findings- Lesson Plans and Observations

Participating teachers were required to develop two engineering design lessons and to implement at least one of those lessons in their middle school classroom during fall 2015. Observations were conducted in 22 of the 24 teachers' classrooms during the fall with 13 of those observations occurring during implementation of a lesson developed specifically for Project TESAL. Five teachers self-reported regarding their implementation of engineering design lessons when observation was not possible.

As an example, the Gingerbread House engineering design lesson plan is provided in Figure 4 and the rubric for assessing that lesson is provided in Figure 5. Engineering design lesson plans developed by participating teachers covered the following topics:

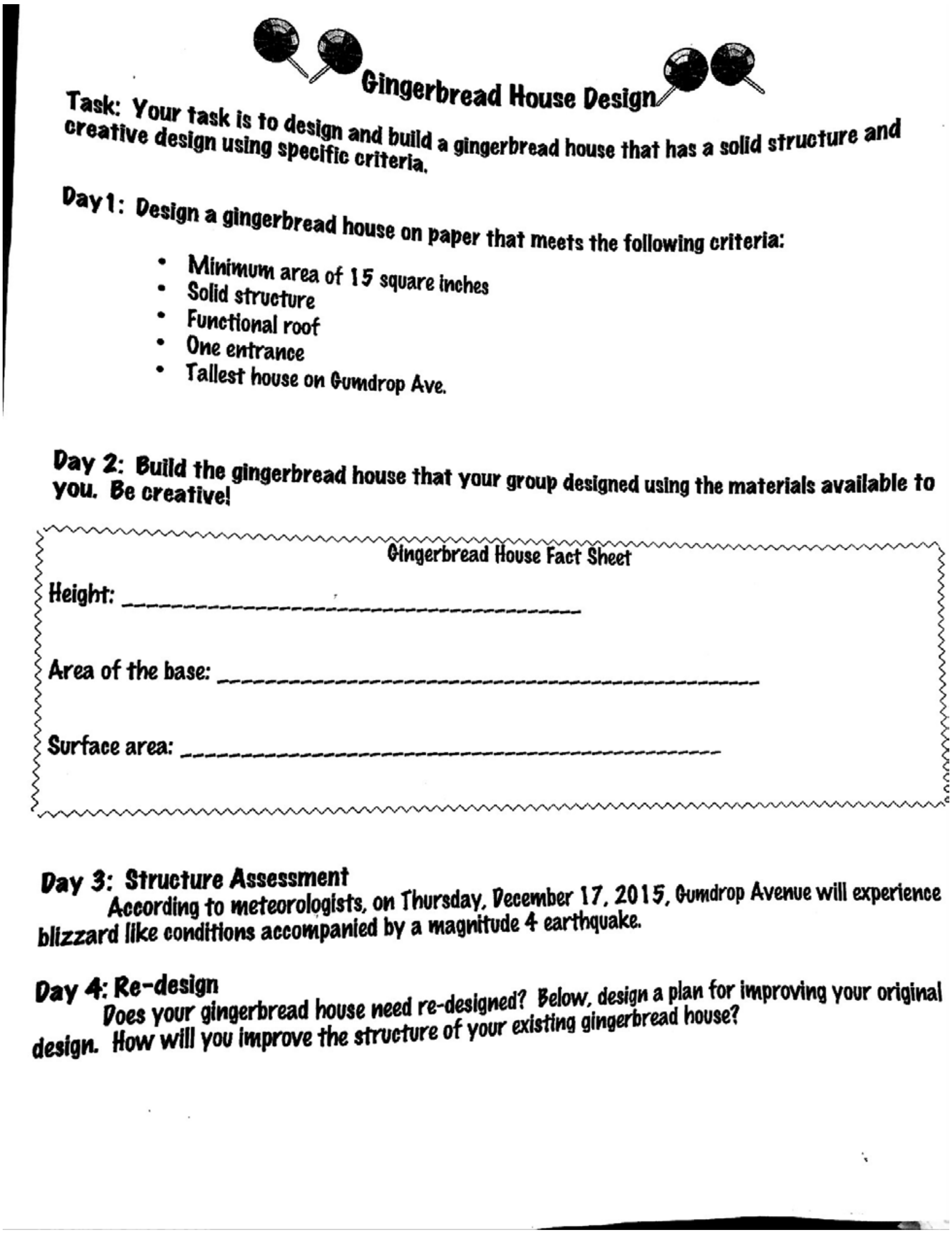
- Design a Roller Coaster (3 science educators, 2 math educators, 2 special educators: 4 schools),
- Design process to make the perfect hard-boiled egg (1 science educator, 1 special educator: 2 schools)
- Design an ice cream cone business (1 math educator)
- Design a healthy meal plan from McDonalds (1 technology educator)
- Design a tall and safe gingerbread house (1 math educator; see figure 4 below)
- Design a skating ramp (1 math educator)
- Design a shoe box that can be made from a single piece of cardboard (1 special educator)
- Design a scalable process to make a non-Newtonian fluid Oobleck (1 math educator, 1 science educator: 1 school)
- Use the design process to select a cell phone provider for a medium sized company (1 math educator)
- Design an air-bag (1 science educator)

Interestingly, we saw co-teaching and collaboration across content areas and across grade levels, on the Roller Coaster and on the Non-Newtonian Fluid Oobleck engineering design lessons. In addition, several teachers delivered more than the single required engineering design lesson plan.

During classroom observations a number of themes emerged. A number of teachers commented on how design based instruction increased the engagement of all students and that an increase in engagement of special education students was observed. One special education teacher in a low performing school first facilitated a design project to make a perfect hard-boiled egg. "*Students went home and asked their parents and grandparents to teach them to boil an egg and practiced with them. They then sat in the classroom carefully watching the water boil timing every step. I had never seen that level of engagement with this group of students. It has made me a believer*". The same teacher then developed a second lesson to design a shoebox from a single piece of cardboard. The students made prototypes and a final scale model design. Two special education students who have had limited success in the classroom designed an innovative triangular prism design – "*whenever they are struggling in class now I remind them of their success on the shoe box project. I am working on design projects to use in the Spring Semester with them now.*"

A number of the math teachers commented on challenges letting go and allowing students to work on more open-ended problems and how rewarding it was to see them succeed. In one math classroom, 6^{th} grade math students performed measurements of the distance around a curved paper roller coaster built by 8^{th} grade science students and the time to traverse the track. Students then calculated the average speed. Students performed repeated runs and calculated statistics for the average and spread of the data. Students were engaged for the entire lesson period and participated actively. Two months after facilitating the roller coaster lesson, this teacher decided to develop her own lesson on building a gingerbread house (see Figure 3). She expressed that she was nervous to try something so hands on but had gained confidence from the previous hands on lesson. During observation the students were engaged and in particular she identified that one of the students in class who does not normally participate was engaged. We observed him taking the lead on measurement tasks and interacting well with other members of his group.

In addition to successful implementation by teachers in their classrooms, it was also evident that teachers felt able to ask questions about content they were unsure of. The most common content areas that teachers felt uncomfortable with were the conversion of potential energy to kinetic energy and how to measure energy. We have developed a series of experiments to attempt to assist in this area and will implement this professional development in the spring.



Gingerbread House Design

Task: Your task is to design and build a gingerbread house that has a solid structure and creative design using specific criteria.

Day 1: Design a gingerbread house on paper that meets the following criteria:

- Minimum area of 15 square inches
- Solid structure
- Functional roof
- One entrance
- Tallest house on Gumdrop Ave.

Day 2: Build the gingerbread house that your group designed using the materials available to you. Be creative!

Gingerbread House Fact Sheet

Height: ______________________________

Area of the base: ______________________________

Surface area: ______________________________

Day 3: Structure Assessment

According to meteorologists, on Thursday, December 17, 2015, Gumdrop Avenue will experience blizzard like conditions accompanied by a magnitude 4 earthquake.

Day 4: Re-design

Does your gingerbread house need re-designed? Below, design a plan for improving your original design. How will you improve the structure of your existing gingerbread house?

Figure 4: Gingerbread House Design lesson

Gingerbread House Design Project Rubric

40 points possible	Professional Engineer 10 points	Apprentice 6-9 points	Engineer in Training 2-5 points	Needs additional Training 1 point
Structure	House has a sturdy structure, entrance and functional roof and a clear design	House has a sturdy structure and a clear design	House stands, but has a sloppy design	House does not stand and candy has no order
Creativity	House shows personality and creativity with a clear design	House shows personality and creativity	House shows some personality and creativity	House is lacking personality and creativity with poor design
Collaborative Effort	Outstanding collaboration with peers and respectful behavior	Moderate collaboration with peers and respectful behavior	Very little collaboration and respect	Lacks collaboration and respect
Participation	Maintained focus on the task, shows attention to detail, has a positive attitude and assists peers	Maintained focus on the task and has a positive attitude	Very little focus on the task and moderate effort	Not focused on the task, complaining and no effort. Eating candy

Figure 5: Gingerbread House Design rubric

Discussion

Project TESAL has been successful recruiting a diverse group of mathematics, science, and special educators, and at engaging them in professional development they find valuable. We have seen very little attrition with only two participating teachers leaving the program in the first year: One for personal medical reasons and the other to pursue an engineering graduate degree. The T-STEM survey revealed strong initial 21st Century Learning and Teacher Leadership Attitudes in this group so it was not surprising these did not increase following professional development. However, the professional development did successfully increase participating teachers' confidence to teach engineering design, their confidence that they can influence their students' STEM performance, and their knowledge of STEM careers, as well as the amount they expect to utilize technology and instruction following STEM best educational practices.

Narrative comments from teachers in the post-professional development survey and focus groups were extremely positive, with teachers identifying several strengths of Project TESAL. Participants particularly valued being active participants in learning, opportunities for collaborating with peers and outside experts around the work of teaching, focusing on subject matter content across mathematics and science and students' learning of that content, and the sustained ongoing nature of Project TESAL where the work teachers did in professional development was fully relevant to their work as classroom teachers. These strengths aligned directly with best practices for professional development and for overcoming the challenges of professional development specifically on math science integration and engineering design instruction [19-23, 27-30].

A key strength of Project TESAL is that the collaborative project team involves Regional Education Service Area personnel who have authentic long-standing relationships with key schools and teachers in the area working closely with university faculty who have deep engineering, science, and mathematics content knowledge as well as education pedagogy, curriculum resource, literacy, and educational evaluation/research expertise. This sort of team is quite unusual in the mostly rural Appalachian area where we work.

The professional development sessions involve engineering design, math/science content, and literacy interwoven seamlessly as the project team design and deliver professional development collaboratively. Part of the vision of this project has been recognition that the engineering design process applies as authentically to the design and redesign of our professional development and to the design and redesign of teachers' instruction, as well as to the engineering design projects teachers engaged their students in. Throughout all of these applications of the engineering design process, evaluation and redesign are critical components that facilitate continuous quality improvement. The project team strives to both model and scaffold this mindset for and with participating teachers.

While substantial strengths were evident, we recognize on-going opportunities for Project TESAL to overcome specific challenges. Valid and reliable assessment of teacher content knowledge coupled with available content expertise of project personnel is a strength. This strength gives rise to a challenge in determining how to address and appropriately scaffold the content needs of the prospective groups. In other words, how much do mathematics teachers need to know about the science content and how much do science teachers need to know about the mathematics content in order for them to be able to meaningfully plan integrated instruction? In the context of somewhat low content knowledge scores and some content deficiencies noted in classroom observations, especially outside of teachers' primary content area, how do we address the content needs in a safe and authentic way? Some participating teachers commented in focus groups on their appreciation of content from outside their area of expertise. However, it is likely that some participating teachers are uncomfortable opening their content knowledge gaps to remediation. We are working to develop an approach modeled on (sports) coaching with individualized specific skills focused training as a way to address this challenge. The main conception is that individualized assessment of content knowledge profiles across mathematics, science, literacy, engineering design, and educational pedagogy can be developed and utilized to target knowledge and skills development at individual, content area group, and whole group levels. We believe that content knowledge tests and classroom observation data, along with relationships built and strengthened through sustained engagement, will allow us to realize the potential in this approach.

Project TESAL was successful delivering valuable professional development and maintaining teacher engagement this year. One key to that engagement was transparent relevancy of engineering design projects to grade-level appropriate mandated mathematics and science content standards and objectives. As we move into a second year of implementation we shift from physical science to life science as the focus for science content standards and objectives. While we were able to identify grade-level appropriate mathematics content within physical science relevant engineering design contexts, this was not always easy to do. The challenge is to answer the question of whether the relevant, substantive mathematics present in, say a 6th-grade science standard, is aligned with the content in the mathematics standards in 6th-grade, and vice versa. Engineering design contexts identified by participating teachers or Project TESAL personnel easily can lead into interesting mathematics and science concepts somewhat above relevant grade-level expectations/topics. The challenge is to develop meaningful applications of grade level relevant content without dumbing down or reducing to rote applications.

As we move forward in this three-year project, we focus next on continuing to identify participating teachers' current knowledge, skills, and attitudes as foundations for constantly adding value to their knowledge base and instructional skill set. Developing new content and engineering design lessons connecting appropriate content standard and objectives in life science and mathematics is a challenge we are currently engaging. We are particularly excited about further developing a system linking individual assessment and individualized skills development to facilitate coaching teachers to strengthen their pedagogical content knowledge and support student learning in engineering design, mathematics, science, and literacy. Finally, we are leveraging relationships with the state Department of Education to acquire student-level standardized test scores for participating and comparison group teachers in a quasi-experimental propensity score matched design. Given the strong evidence of impact on teachers and implementation of engineering design lessons by teachers with their students, we have reason to be optimistic that this will reveal positive impact on student learning.

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Appendix: Project TESAL Daily Agenda for Summer Workshop and Fall Follow-up

Summer Day 1 Agenda
8:30 AM Housekeeping
9:00 AM Evaluation Surveys, Content Knowledge Tests
11:00 AM TED Talk – Dan Meyer
11:30 AM Lunch (Discussion of Shopping Problem)
12:15 PM Group Share Out
12:45 PM Draw and Label Diagram of Engineering Design Process
1:05 PM Discuss Engineering Design Process/Begin Rollercoaster Design.
2:55 PM Assign Homework (Develop a Lesson Plan Using Everyday Activities That Poses a Problem with Many Solution – Mirrors Shopping Problem)
3:00 PM Adjourn

Summer Day 2 Agenda
8:30 AM Reviewing Feedback; Overview of Project Timeline and Deliverables
8:45 AM Question/Answer Period on Homework
9:00 AM Continuation of Working on Project
10:15 AM Gallery Walk/View Everyone's Project
10:30 AM Overview of Engineering Report Template
10:45 AM Write an Engineering Report (One Per Group)
11:45 AM Lunch (Discuss Redesign and How Content Can be Brought In)
12:30 PM Overarching Project Goals
12:45 PM Technology Training on Distance Collaboration (Google Hangout and Google Docs)
1:45 PM Rollercoaster Redesign; Add to report
2:55 PM Assign Homework (Pick One Lesson Plan Per Group from the Homework/Begin Developing That Lesson Plan)
3:00 PM Adjourn

Summer Day 3 Agenda
8:30 – 8:45 AM Housekeeping (15 min.)
8:45 – 9:15 AM Content-specific groups (30 min.)
9:15 – 10:00 AM Literacy standards (45 min.)
10:00 – 11:00 AM Group lesson - Orange
11:00 – 11:30 AM Instruction as design process and lesson template
11:30 – 12:15 lunch and discuss different student data
12:15 – 12:45 Journal Prompt – Rich Data
12:45 – 1:15 How to write a design brief
1:15 – 2:15 Group lesson - Lime
2:15 – 2:55 Revisiting the Rollercoaster Lesson
2:55 – 3:00 Finish

Summer Day 4 Agenda
8:30 – 8:45 Housekeeping
8:45 – 9:45 Group Lesson: Tangerine
9:45 – 11:30 Work on Rollercoaster Extension;
Discuss: time requirement and instruction manual

11:30 – 12:15 Lunch - Discuss article assigned for reading last night
12:15 – 2:15 Literacy Integration across content areas
2:15 – 2:55 Work on Rollercoaster Extension
2:55 – 3:00 Wrap-up

Summer Day 5 Agenda
8:30 – 8:45 AM Housekeeping
8:45 – 10:15 AM Build and Test Roller Coaster Models
10:15 – 10:30 – BREAK
10:30 – 11:30 Group lesson: Grapefruit
11:30 – 12:15 Lunch and discuss
12:15 – 12:45 Talk about Content Literacy Article – talk in content groups
12:45 – 1:45 Group lesson: Lemon
1:45 – 2:55 Literacy Integration: Writing Design Briefs
2:55 – 3:00 Adjourn
Homework: Brainstorm rollercoaster lesson ideas: Can do main task (rollercoaster) and do offshoots related to extensions, investigations related to specific content goals

Summer Day 6 Agenda
8:30 – 8:45 Housekeeping
8:45 – 9:45 Grapefruit
9:45 – 10:45 Team/Consensus building
10:45 – 11:30 Video
11:30 – 12:30 Lunch (Discuss lesson plan; start developing0
12:30 – 2:30 Curriculum Resources: Jason Project Workshop
2:30 – 2:55 Assignment: Explore Jason Project
2:55 – 3:00 Adjourn

Summer Day 7 Agenda
8:00 – 8:45 Housekeeping
8:45 – 9:15 Literacy Integration
9:15 – 10:30 Content Breakout Groups: Science- Guided Inquiry, Math- MEA
10:30 – 11:30 Lesson Plan development
11:30 – 12:15 Lunch (Read article to discuss in content groups tomorrow)
12:15 – 2:00 Lesson Plan development
2:00 – 2:30 State Department of Education Speaker
2:30 – 2:55 Lesson Plan development
2:55 – 3:00 Adjourn

Summer Day 8 Agenda
8:30 – 8:45 Housekeeping
8:45 – 9:15 Literacy
9:15 – 9:45 State Department of Education Speaker
9:45 – 10:15 Content Breakout Groups – article discussion
10:15 – 10:45 Group Discussion – meeting needs of all students
Journal prompt: what are strategies for scaffolding these activities for students who may need it? What are strategies for extending or enriching these activities for students who may need it?

10:45 – 11:30 Lesson Plan development
11:30- 12:15 Lunch (Read article to discuss in content groups tomorrow)
12:15 – 1:15 Team/Consensus Building
1:15 – 2:55 Lesson Plan development
2:55 – 3:00 Adjourn

Summer Day 9 and 10Agenda
8:30 – 8:45 Housekeeping
8:45 – 2:55 Lesson Plan development/Evaluation Surveys/Focus Groups
2:55 – 3:00 Adjourn

Fall Follow-up Agenda
8:30-8:45 Participant Evaluation Input: Stickies re: What questions do you have about Project TESAL? What do you want to learn today? (These will be processed and addressed today)
8:45 – 10:00 Reinforcing the Design Process including a TED Talk and task for participants to complete
http://www.ted.com/talks/amos_winter_the_cheap_all_terrain_wheelchair/transcript?language=en#t-51576 Watch Professor Amos Winter a Mechanical Engineering Professor at MIT discuss the development of a cheap all-terrain wheelchair. Discussion of video including focus on design process, design criteria, design constraints, evaluation of design against criteria and constraints. Literacy assignment to “describe in words and sketches how you might improve on the designs in the video”.
10-10:30 Reinforcing Literacy Integration
10:30-10:45 Discussion re: Participant Evaluation Input
10:45-12:00Group conversation re: literacy project planning including identification and analysis of design process citations and discussion of what student work/data to collect and include.
12:00-1:00 Lunch
1:00-1:30 Example re: utilizing ATLAS protocol to examine student work
1:30-2:00 Participants apply ATLAS protocol to their students' work samples
2:00-2:30 Redesigning lessons informed by student thinking
2:30-3:00 Participants peer evaluate lesson plans