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Impact of Attending a Research Experience for Teachers Program with International and Societally Relevant Components

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Introduction

We sought to bridge the divide for teachers and their students between secondary science and mathematics content, on one hand, and the engineering of solutions to real-world societally-relevant problems, on the other hand. The expected outcomes for the Research Experience for Teachers: Energy and the Environment project* (RET) included:

1. Teacher knowledge and attitudes toward science and engineering will improve as a result of participating in ongoing engineering research projects for six weeks during the summer and attending an International Summer Energy School.

2. Teacher attitudes toward science and engineering will improve as a result of experiencing problem-based learning (PBL) and engineering design with constraint activities as learners and teachers will subsequently use design and PBL pedagogies in their classrooms.

3. Teachers will more fully appreciate relationships that tie science fundamentals to technology applications and economic development, and become more forceful and convincing advocates for sustainable energy practices and science, technology, engineering, and mathematics (STEM) education.

RET participating teachers (n=23) engaged in cutting-edge engineering research at West Virginia University in the United States, attended an International Summer Energy School at the University of Birmingham (United Kingdom), and developed design and problem-based learning units based on those experiences to deliver to their students. The international component and a strong emphasis on pedagogical support for lesson development and implementation were novel elements not typically found in RET projects. We found that engineering research and international experience around sustainable forms of energy along with participating in engineering design with constraint activities were transformative for teachers. Participating teachers came to better understand engineering and the design process, and made connections among mathematics content, science content, and real-world applications to societally-relevant problems that they previously did not recognize. This transformation carried into their classrooms through design and problem-based learning units, and through increased advocacy for sustainable energy solutions and STEM educational and career paths.

Relevance and Integration in Secondary Mathematics and Science Instruction

Mathematics educators recognize the need to develop a more relevant curriculum for students and are exploring new approaches that connect mathematical concepts with real life. Science educators are also increasingly situating science in societally-relevant contexts where scientific knowledge from different areas can be integrated to solve meaningful problems. There is increasing consensus around the need to make connections across science and mathematics

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explicit; to teach in an integrated manner so that students establish math-science connections through active inquiry in authentic contexts. Our efforts to make mathematics and science instruction more relevant and integrated for teachers and their students through the utilization of societally-relevant contexts and problems grew out of a reading of the literature briefly summarized here.

One of the major concerns of the mathematics education community is a lack of pedagogical practice that establishes connections between mathematical concepts and real-world applications[1–5]. The opportunity to develop such connections has been explored through the types of problems introduced in the classroom as well as the way solutions to these problems have been approached. The benefits of establishing real-world mathematics connections include increased student understanding of mathematics concepts and increased motivation for learning mathematics [1]. Disconnects between mathematics ideas and their application have emerged from research on how students make sense of problems they solve in the classroom. For example, De Corte et al. [3] found that students rarely utilized their real-world knowledge and considerations when they solved problems in the classroom; students often engaged in non-realistic solutions without considering realistic limitations or the existence of multiple solutions. After interviewing and observing teachers, Gainsburg [4] concluded that the teachers considered a wide range of practices they employed in the classroom to be "real-world applications" but they were not consistent across time. Teachers often presented problems to students in ways that did not require students' active input to the "real-world" solution of those problems. Often teachers were concerned more with the communication of specific mathematical concepts, rather than the contexts in which those concepts were presented and their significance for solving meaningful problems.

Science educators voice concerns similar to those of mathematics teachers. They often see disconnects between how science is taught in the classroom and its relevance to everyday problems [6-8]. The way science has been taught traditionally in the classroom has been quite isolated from real-world applications. Bouillion and Gomez [6] see this way of teaching science leading to classroom learning that is not applicable to life learning. This disconnect may manifest in a lack of relevance for students of their classroom learning for their everyday lived experience. Looked at another way, this disconnect may be a result of schools or teachers failing to see how students' personal experiences hold value in the process of learning science [6]. To avoid this disconnect, science education must reach beyond the classroom and explore concepts in more valid and authentic contexts that are more motivating for students and allow students to leverage their lived experience [8]. Once a real local problem is brought into the classroom, students are more likely to learn scientific concepts through that relevant context. Such an inquiry overcomes the separation between "community-based" and "school-based" forms of science.

Mathematics and science content instruction should be integrated and placed in authentic contexts that promote discovery of natural relations between these two disciplines while at the same time bringing real-world contexts into the classroom [9-10]. Literature on mathematics and science education reform reveals the argument that by establishing a link between the two subjects, teachers can foster student motivation and lead students to better understand a wider range of connections among scientific and mathematical concepts [5,11]. Such a focus on integration goes beyond the accumulation of mathematics and science facts and concepts and transforms into the notion of using mathematics and science to make sense of the world. While this argument focuses on the significance of this trend for students learning, Frykholm and Glasson [10] emphasized that the first step is that "teachers [must] understand the contexts that hold potentially significant mathematics and science connections" (p.130). Once such connections are established, and teachers feel comfortable with both the science and the mathematics related to those contexts, they can effectively bring those contexts into the classroom.

Meaningful Problems as Contexts for Mathematics and Science Learning

The National Research Council [12] has urged the adoption of curricula that encourage students to perform hands-on experiments in the classroom to build mathematics and science knowledge and skills that will last far beyond the point of instruction. Specifically, students are expected to: design and conduct a scientific investigation; use techniques to gather, analyze, and interpret data; and use mathematics in all aspects of scientific inquiry. The National Science Foundation [13] has supported the use of problem-based learning (PBL) as an approach to improving science, technology, and mathematics education. PBL is an approach to instruction that increases students' responsibility in learning and changes the role of the instructor from the main source of knowledge to the facilitator of learning [14-15]. Students are given a more collaborative role in the classroom and tasked with applying prior knowledge and constructing new knowledge in the process of solving real-life problems [16]. PBL is a potential solution to the lack of real-world, hands-on experience in K-12 mathematics and science programs [14, 17]. Students engaging in PBL lessons gain content knowledge and skills required to effectively problem-solve and enhance their capacity for self-teaching [16-18]. Kolodner et al. [17] showed that students engaged in PBL demonstrated science competence levels at or above students engaged in traditional teaching methods.

The nature of problems introduced through PBL is very different than the often artificially manufactured problems in traditional classrooms. PBL problems are both ill-structured and multidisciplinary [19-21]. This problem format offers opportunity to apply skills and knowledge across different disciplines with multiple constraints. In the process of developing a solution, students engage in evaluation, cooperation, and communication [21]. As learners critically analyze a problem, they often have to consider multiple constraints provided by the authentic problem context, which is contrary to traditional problems that often exist in a vacuum. Barrow [19] emphasized that the skills required for solutions to realistic problems are valued in the real world.

The presence of constraints and complexities arise from the real-world authentic nature of the problems presented in PBL [20-21]. This authentic context notion is a consideration for both mathematics and science educators. The benefits of folding authentic contexts into classroom tasks include providing an opportunity for greater engagement of students in their own understanding of realistic situations [22] as well as developing their own scientific reasoning for those situations [20]. The practical application of these problems is emphasized on multiple levels[23]. Problems presented to students as contexts in PBL are generally ill-defined and do not require a specific order of steps to be followed [20], in contrast to traditional methods that require students' to identify a single correct solution [19].

The PBL approach to learning places both learners and teachers in a new position. Teachers have to make a transition from being providers of knowledge to being facilitators of learning [16].

Rather than being the evaluator of whether an answer is correct or not, emphasis is placed on the interpretive role of the teacher in understanding the adequacy of multiple potential solutions. Teachers need to move away from guiding students to a correct answer and move toward emphasizing student engagement [24]. The teacher's focus should target encouragement of their students' own reflection on their reasoning as well as interpretation of problem situations [25]. 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 interpreting specific ideas and their connections to the problem at hand [26]. This type of facilitation requires significant scaffolding mechanisms for effective learning to take place [27]. The new role of the teachers includes carefully selection, preparation, and implementation of those scaffolds [16, 28]. Lack of sufficient guidance will lead to less effective and less efficient learning [23]. In addition to the pressure for teachers to be guides of learning, effective facilitation of the learning process requires the teacher to coordinate multiple funds of knowledge including subject matter knowledge, pedagogical content knowledge, and deep understandings of the authentic contexts engaged [29].

Engineering Design for Content Integration and Solution Processes

Engineering is an appropriate context within which to integrate scientific and mathematical concepts [30, 31], and the engineering design process can be appropriately incorporated into both mathematics and science curricula [32]. Such integration allows students to gain experiences related to their everyday life that focus on the process of finding a solution rather than the solution itself [5, 33, 34]. Students recognize relationships and direct linkages between their classroom experiences and real-world practices when they engage in hands-on approaches through engineering design [31, 32]. Engineering design integrates smoothly into PBL approaches when potential solutions to problems are designed, built, evaluated, and redesigned iteratively.

Because of these potential benefits, a number of different outreach programs that target the incorporation of engineering into K-12 education have been implemented [35, 36]. According to Brothy et al. [35] engineering education incorporates STEM knowledge and engages students in tasks associated with developing solutions to problems. Those activities include analysis tasks, design, and troubleshooting components of the solution process. Design and testing activities are essential as they emphasize both understanding and application of scientific principles [37]. The traditional approach to teaching science is enhanced by projects that engage students in such design activities as part of solution development.

While incorporation of authentic problems through PBL and engineering design contexts benefit students', the question remains how teachers can be adequately prepared to facilitate and guide such learning [35]. Very few K-12 teachers have an engineering background [35] and few students and teachers have an understanding of what engineers do [38]. Teacher professional development should incorporate engineering into K-12 education [33, 38]. Pre-service teacher programs with some emphasis on engineering contexts and engineering design do exist [35, 39], but in-service teachers have little opportunity for such exposure. Current teachers are typically uncomfortable teaching content that they do not possess good understanding of and may be afraid they will not be able to answer students' questions [35]. This challenge is compounded in PBL approaches where students are taking ownership of inquiry. In-service teachers need strong preparation for the synthesis of mathematics, science, and engineering before they can effectively engage in teaching that targets such integration [30].

Blending engineering with the core curriculum requires mathematics and science content knowledge expertise as well as pedagogical content knowledge. When such funds of knowledge are well developed, additional exposure to engineering and engineering design allows teachers to gain experience anticipating the kinds of difficulties and questions learners might pose in the classroom. Kimmel et al. [33] emphasized the urgent need for professional development training to prepare teachers to incorporate mathematics and science within the engineering context. Such initiatives need to address multiple aspects of teacher preparation including content knowledge in the complementary content area (i.e., mathematics for science teachers, science for mathematics teachers) and how the engineering context can serve as an ideal platform to incorporate those areas. Teachers may require additional training to feel comfortable with their new role as guides to learning rather than providers of correct answers. Even more importantly, teachers need to be presented with opportunities to apply their new knowledge and skills in hands-on activities prior to returning to their classrooms in order to be prepared for incorporating those types of activities into their teaching [37]. The RET program described here incorporated novel components not typically found in RET programs (international experience and strong pedagogical support) in order to prepare in-service teachers to effectively integrate mathematics and science instruction in PBL and engineering design contexts.

Research Experience for Teachers Program

The American Society for Engineering Education recommends six guidelines for improving engineering education: Hands on Learning, Interdisciplinary Approach, Standards, Use/Improve K-12 teachers, Make Engineers "Cool", and Partnerships [36]. By selecting hands on design challenges, integrating engineering into mathematics and science classrooms, providing research opportunities and engineering background to middle and high school teachers, and involving graduate students and engineering professors in the classroom, we addressed all of these recommendations except developing standards. We used a combination of design based learning (design of a bridge and boat) and problem based learning (estimation of the number of solar panels to provide all the electricity required for the state of West Virginia) to address these challenges. The inclusion of social relevance was an important part of our program. Teachers were introduced to the US National Academy of Engineering (NAE) grand challenges. The hope was teachers would understand and relate to their students the important work that engineers do in improving society. This is especially important for underrepresented groups in engineering, minorities and females [36]. While the grand challenges provided background on what engineers could accomplish in the future, the focus of our program was on the environment and exercises that could engage students to make a difference in their local contexts. Our state is a large producer and user of coal and the word coal is somewhat synonymous with energy to many in the state. We chose alternative energy sources (e.g., wind, solar, hydrogen) as an evocative topic that would spark significant discussion and interest from both teachers and students.

The main emphasis was on facilitating mathematics and science teachers' integration of their two content areas with engineering in sustainable energy contexts to develop PBL units as vehicles to bring what they learned to their students. To this end, mathematics and science teachers collaborated in cross-disciplinary teams throughout the RET. This RET project had three main components that all participants engaged in. These included engineering research where participating teachers worked as part of a university research team conducting ongoing research projects led by engineering university faculty and advanced graduate students. These projects included research on alternative fuels, climate change, coatings for solar energy, and fuel cells. The second component was PBL and design-based activities where teachers were active learners who designed, built, and evaluated specific artifacts as solutions to specific problems and subsequently developed PBL units to be implemented in their classrooms. Engineering faculty and graduate students visited teachers' classes when they implemented these lessons to provide feedback. The third component took participants on a ten-day trip to the United Kingdom, during which teachers expanded their research knowledge by observing ongoing research practices and projects at the partner university. As a part of the trip, participants visited local secondary schools where they observed classrooms and engaged in discussions with local teachers to exchange experience and views related to science and mathematics teaching. Often, teachers observed PBL lessons as approached by teachers in the UK. Participating teachers wrote reflections after their school visits where they examined their experiences as a generator for teaching practice transformation. The direct observations allowed teachers to draw parallels between what they saw and their own classrooms in the US.

A key difference between science and engineering is the inclusion of constraints in the engineering process. Participating teachers completed two design based activities guided by engineering professors and advanced graduate students, one in the US and one in the UK. The first was a beam building competition based on a project freshman engineering students complete in the UK. Teachers also built boats powered by a candle [40]. In each of these projects, constraints were introduced by limiting materials and imposing weight and budget limitations. These activities allowed teachers to step into learners' shoes and tackle problems that were not step-wise oriented and required a number of different skills and types of knowledge to be applied in order to develop and refine potential solutions. These activities allowed participants to experience firsthand what their students will face in the classroom and realize the importance of providing well-planned and meaningful support mechanisms to guide students rather than giving them the solution to the problem. By being learners themselves, they acquired valuable knowledge and skills to address elements imperative for a well-developed and effective PBL unit. Their design-based activities were supported by scientific and mathematical concepts that were introduced during their engineering research experiences, further developing participants' understanding of relationships across all three. Teachers often utilized their familiarity with those new concepts and contexts from their engineering research when building their own PBL units.

The interconnectedness of the different RET elements was purposefully designed to facilitate teachers building a holistic picture of how engineering provides a platform for integrating mathematics and science to study and improve societal problems. Establishing those connections among mathematics, science, and engineering design in the classroom is vital in any attempt to provide students with adequate background to further develop their knowledge and skills in these areas. The research projects introduced practical applications currently underway for environmental and energy sustainability improvements and offered examples of how classroom learning can be taken outside of the classroom into real-world applications. Thus the three components built a continuum of connections among content knowledge, classroom practice, and real-world application for teachers to utilize in their practice.

Evaluation Design and Metrics

Our expected outcomes for this project were that:

1. Teacher knowledge of and attitudes toward science and engineering would improve as a result of participating in ongoing engineering research projects for six weeks during the summer and attending an International Summer Energy School.

2. Teacher attitudes toward science and engineering would improve as a result of experiencing problem-based learning (PBL) and engineering design with constraint activities as learners and subsequently using design and PBL pedagogies in their classrooms.

3. Teachers would more fully appreciate relationships that tie science fundamentals to technology applications and economic development, and become more forceful and convincing advocates for sustainable energy practices and STEM education.

The mixed methods design for evaluation of this project included both quantitative and qualitative metrics. Quantitative metrics included content based assessments that participants completed at the beginning of each year to provide a baseline understanding of their content knowledge. Originally, the Force Concept Inventory and the Calculus Readiness assessment were administered to all participants. In 2011, a chemistry content knowledge instrument was added to the quantitative measures. Participants also completed a pretest and posttest with Likert scale items targeting their attitudes and understanding regarding the utilization of PBL as a pedagogical approach and a number of non-PBL items including understanding of the connections between science and mathematics fields, importance of engineering, and certain concepts related to energy renewal and environmental sustainably.

In an attempt to closer examine the impact of the program, a number of qualitative metrics complemented the quantitative portion of the evaluation. A section of the pretest and posttest consisted of open-ended questions where participants constructed responses based on their current understanding of the issues addressed. These were completed both at the beginning and at the end of each cohort. In addition, semi structured one-on-one interviews focusing on the teachers' perceptions regarding different aspects of the RET were conducted. Both the open ended questions from the pretest and posttest and the interviews were analyzed to determine emergent categories through open coding of participant responses. These data sources were examined for common areas of impact across participants and across cohorts. The individual comment was the unit of analysis as a comment ranged from a single phrase to a short excerpt consisting of a number sentences referring to the same concept. Excerpts were selected from interview transcripts to exemplify individual responses fitting the various categories and to give voice to participants' perspectives regarding impact. The qualitative portion allowed for a deeper understanding of project impact and insight about the development that teachers experienced both personally and professionally. Specifically, participating teachers reflected in detail on the multiple ways in which their personal knowledge and teaching practice were affected by RET experiences.

Participating Teacher Demographics

A total of 23 teachers participated in the RET project over the three years of this initiative. Five of those teachers were participants in two consecutive years. Four participated in 2010 and returned in 2011. One participated in 2011 and 2012. The returning teacher-participants had a special role in terms of providing support for new participants. They facilitated the orientation and some of the formal instruction, especially related to PBL.

Figure 1 presents participants' age in years by cohort. The overall age distribution is bimodal with the greatest number of participants in the youngest and oldest age ranges. Diversity in teaching experiences across cohorts was also evident as shown in Figure 2. Participant diversity in terms of science and mathematics teaching expertise is provided in Table 1. Diversity in age, experience, and mathematics/science background was a definite strength of the program and was maintained across cohorts. In addition, teachers from different fields collaborated on projects during the development and implementation stages of PBL units. Participants were able to enter into discussions and support each other with their diverse backgrounds, sharing with each other perspectives they might not otherwise have been exposed to.

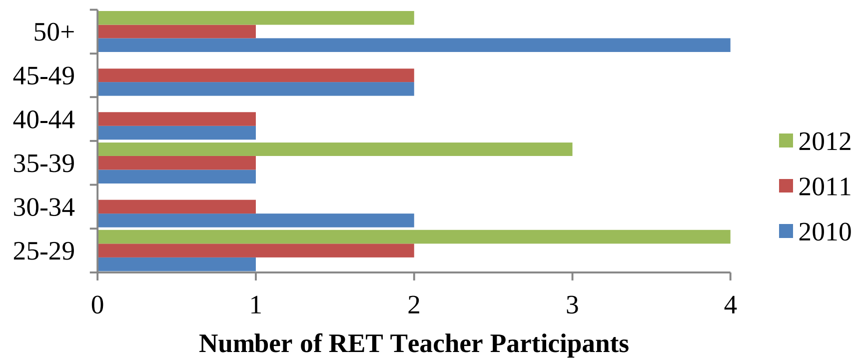

Figure 1. Age (in years) across RET Teacher Cohorts

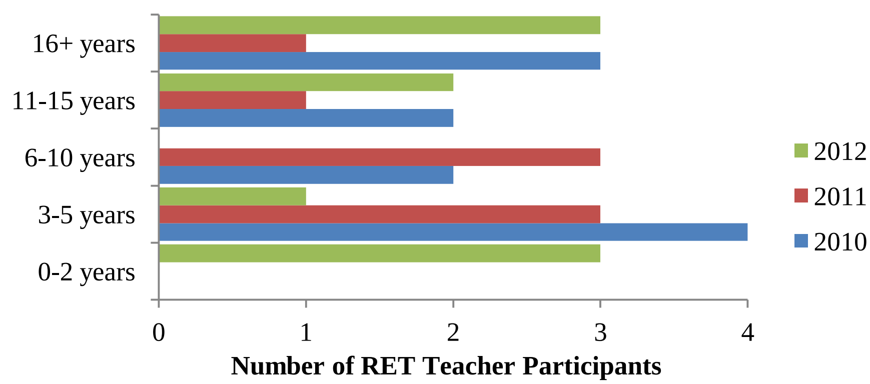

Figure 2. Years of Teaching Experience across Cohorts

Table 1. Number of Participating Teachers Covering General Content Areas

Content Area	2010	2011	2012	Total
Science	6	5	6	17
Mathematics	5	3	3	11

Table 2 displays the number of teachers and the grade level that they taught while participating in the RET. The majority of teachers taught grades 9 through 12, but some had experience teaching grades 7 and 8. Most teachers taught in more than one grade level. Participants were able to generate a wide range of ideas for their projects based on the diversity in the curriculum aligned with each grade level knowledge and skills requirements and expectations.

*Table 2. Number of Participating Teachers Covering Each Grade Level**

Grade	2010	2011	2012	Total
7	3	2	1	6
8	3	2	1	6
9	6	4	6	16
10	5	5	7	17
11	6	6	8	20
12	8	3	8	19

*Note: Numbers do not sum to number of participants because teachers cover multiple grades.

The participants also taught a wide variety of courses. A few of the teachers taught both science and mathematics (for example physics and mathematics) and some were involved in team teaching opportunities where science and mathematics teachers were both present in the classroom and co-taught some instructional units together.

Findings and Interpretation

Figure 3 below summarizes categories and themes that emerged from our qualitative analysis and serves as an organizational summary of our findings. Primary themes bracketing and intertwined throughout all of the categories were the real-world research experience teachers' gained and their intent to bring their experiences into their classroom implementation. The five categories in the middle of figure 3 were the main areas of impact identified by teacher-participants. As these categories included both quantitative and qualitative measures, quantitative and qualitative results are discussed together to explore the richness of those experiences as reflected by the teachers themselves. In addition to gaining knowledge and skills in these areas, teachers elaborated on ways these newly developed competencies will enter their classrooms in the immediate future as they attempt to bring their experiences from the RET into their classroom to introduce their students to different perspectives. Teachers consistently expressed their strong beliefs that this experience would change their teaching practice in multiple ways, including pedagogical approaches, expansion of the content/curriculum, and relevance to social, environmental, and energy-related issues.

The following five categories emerged directly from qualitative content analyses of participating teacher interviews and bear directly on the impact of the RET experience:

1. Research experience: Participants reflected on the impact of active involvement in authentic ongoing research; they became more aware of the realities and implications of conducting research.

2. Content knowledge: Participants reflected on their improved understanding and gains in the areas of content knowledge related to mathematics, science, and engineering.

3. Problem-based learning: Participants developed practical skills experiencing design and PBL activities as learners then creating relevant PBL modules incorporating new approaches as well as new mathematics and science content.

4. Mathematics-science connections: Participants identified newly established connections across fields (mathematics, science, and engineering) as a way to better understand social environmental issues. In addition, they commented on the importance of bringing those connections into the classroom in the form of real life scenarios and problems.

5. Cultural awareness: Participants reflected on different cultural perspectives related to energy sustainability and environmental issues, and increased understanding of the importance of those issues. They also described increased insight into different teaching approaches in science and mathematics.

Even though these categories are listed as distinct areas of impact, it is important to note that these components were interconnected making it somewhat difficult to discuss each separately. The underlying relationships that participants established as a result of their RET experiences are reflected in the discussion below. Further, the connections formed across different elements are evident from teachers' responses and are incorporated into the overarching exploration of the benefits of the RET program.

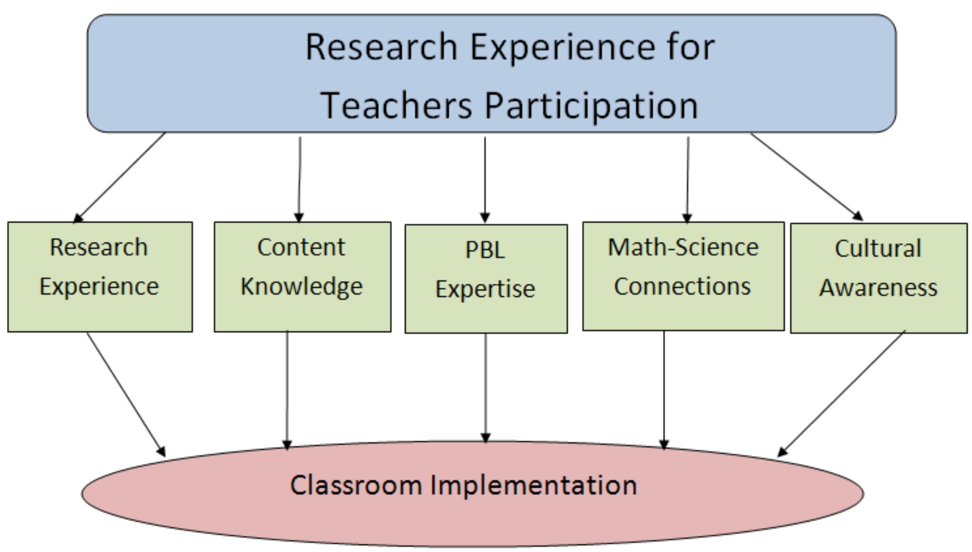

Figure 3. Themes (top and bottom) and categories (middle) that emerged from qualitative analysis.

A significant portion of the six-week summer session was dedicated to teachers participating in ongoing engineering research projects. Participants reflected on the impact of these experiences in one-on-one interviews at the end of the program. Participants developed an improved awareness for the process of conducting real life research and its role in the world of science. One participant noted, “I feel like it was extremely beneficial just seeing the process.” The teachers achieved a better understanding of the true nature of the research procedures as they noted them being demanding and time consuming. One teacher gave insight about his new understanding of doing research, “it's one of the aspects of design or research; you have to understand that sometimes it's a slow process, maybe a lot of little steps you have to go through before the big thing is done.” As evident from the teachers’ feedback, having the personal experience of being involved in these activities led to a better understanding of the demands and inputs necessary for conducting research. These experiences brought a greater appreciation for the research process itself.

Teachers took part in two design activities concurrent with their research experiences. Participants immersed in the process they referred to above and brought their most recent experience from the research lab into the design process tasks. The teachers stepped into their students’ shoes and explored possible weak elements of their units. One teacher noted:

> It was neat for me to go through that process even though I am a teacher, but just learning a lot about it the same way I'm going to ask the students to learn about it. So that was helpful for me as a teacher to see where they're going to have problems and how we can improve the nature of what we're going to ask them to do.

These reflections support the argument for active hands-on activities incorporated into professional development opportunities [41]. The teachers were not just passive recipients of information but took an active role and ownership of their learning. Schaefer et al. call for hands-on activities in the classroom in order for students to develop a better grasp of real-world applications[31]. Here, the teachers incorporated this very same principle into their own professional development. They were absorbed into the research and by learning about the process and engaging with it firsthand they became more comfortable bringing the same concepts into their classroom. The idea of having such an experience as a learner was enriching. The value of this experience was multilevel: as the teachers were taken out of their comfort zone it also opened their eyes to opportunities and possibilities in the world of science they had not previously considered. One teacher shared her amazement, “the research part, being exposed to other people's research in a field that I thought didn't exist to be so great, it was kind of humbling.” This engagement in the research process allowed them to gain real life experience in the field of scientific research and also reflect on the importance of this process.

These activities allowed teachers to gain direct exposure to engineering and engineering design that few have the opportunity to experience [35]. Participating teachers experienced those contexts as novices, which prepared them better for the questions and issues that will arise in their own classrooms. Having that experience as learners allowed them to form expectations about the dynamics of PBL and supports they need to provide their students.

The research activities also established a portal for emphasis on connectedness between mathematics and science. Participants shared their reassured importance of this integration. Teachers’ perceptions related to that connectedness were examined through four Likert-scale items completed before and after the RET (see Table 3). These Likert-type items were scored on a scale from 1 (strongly disagree) to 5 (strongly agree). The initial scores showed very high appreciation for these connections. However, there was still an increase in the mean score for two of the items. Participants scored slightly lower on the posttest on the third item in the set "*Science and mathematics instruction is necessary for economic development.*" This could be attributed to lack of a discussion during the RET relevant to issues of economic development and the role of mathematics, science, and engineering education. The score for the fourth item did not change from pretest to posttest.

Table 3. Mean (Standard Deviation) for Likert-type attitude items pre- and post-RET

	Pretest		Posttest	
	Mean	SD	Mean	SD
I see connections between my content area and global energy or environmental issues.	4.43	.879	4.68	.476
I believe that approaching science, mathematics and engineering instruction from a global perspective is important.	4.75	.441	4.86	.356
Science and mathematics instruction is necessary for economic development.	4.75	.441	4.71	.460
I believe that teaching science and engineering is of central importance in order to cope with future global challenges.	4.82	.390	4.82	.476

The new connections that participants developed and the increased awareness of the presence of those relationships were more strongly evident in participants' open ended survey responses and reflections during the one-on-one interview. One mathematics teacher may serve as an example of change that took place for many RET participants. At the beginning of the program her open-ended survey response was, "there is not a clear cut relationship in my mind between mathematics and global energy and environmental issues." However, at the end of the program she said, "there is strong relationship between science, engineering, mathematics and global energy/environmental issues." This transformation was remarkable. Teachers saw mathematics and science classrooms as the places to initiate understanding of these connections. While some of the participants failed to see those relationships prior to their RET experience, many reflected on the different ways they began to perceive the world as a result of the new experiences they had.

This connectedness across the fields of mathematics, science, and engineering was initiated and further developed by participants' exposure to new content. The authentic nature of the research situated in environmental contexts often placed teachers outside of their comfort zone. They were confronted with mathematics and science applications that were unfamiliar to them. In these new experiences, participants discovered new connections and identified innovative ways to incorporate them into their classroom. One mathematics teacher reflected on his experience, "I got to see a different perspective. I got to see how mathematics is tying into other things." Establishing these connections was critical for the design activities in which the teachers engaged. Bringing mathematics and science together was key to successful completion of the task at hand. One science teacher elaborated, "I think with the beam that was really [obvious], especially that mathematics tie in". Building these relationships seemed to be an area of concern as another participant shared:

> I feel like my kids aren't getting that true connection between the two, like they're not seeing the bigger picture. We do mathematics in physics, like calculating velocity or whatever but to truly see that in the planning phase of the design based project or design based learning project was a huge thing for me.

With new knowledge and experience gained from the RET, participating teachers made conscious efforts to incorporate new content and approaches into their classrooms so that the RET would impact their students as well. One mathematics teacher was very open about what she will change in her future practice, "I try to use the science that I am learning to teach the mathematics as opposed to just following up the mathematics with a cool lab."

Teachers shared their intent to bring their new math-science connection awareness into their classroom. One participant noted that she wanted her students to see, "here's what you can do with science, here's what I learned, here's how fascinating science can be in this application and this application, worldwide, real life experiences that give meaning to the chemical equation and give meaning to the scientific process." Many of the participants expressed similar ideas that through their involvement in the process of conducting research their respect for and awareness of its value had changed. With their new understanding of scientific research, participating teachers plan to engage their students in activities from the RET to spark their interest in science, engineering, and conducting research.

A key element here was not only evaluating this connection but also implementing these new relations in the classroom where students could experience firsthand how different fields merge across similar concepts. One of the participants took on that responsibility readily:

> [It] would be really neat for me to be able to talk to my students about that and say it's not just being a physicist or a mathematician like there are a million different fields that utilize [math and science] like you have to be strong in algebra and you have to be strong in science and other concepts before you can go into these fields.

Other participants were both open to building these connections and to exploring new ways to introduce them to their students as "there are ways that you can incorporate mathematics and engineering and science into your classrooms." Integration of those fields was recognized by teachers as vital for the expansion of students' knowledge and understanding of the world around them. One participant was very specific about the impact of their experience:

> My experience in the RET this summer has motivated me to make real-world connections with the concepts that I am teaching in my lessons. I now feel that I will be able to relate my mathematics content and objectives to specific areas of science and engineering. This will help create a real-world connection for my students.

These reflections provide insight into how the engineering context in which teachers were immersed provided an excellent platform for integration of mathematics and science [30]. One participant was very explicit, that "engineering is a subject that shows the relationship between mathematics and science.", while many participants related similar understandings and gained better awareness not only of the connections that exist across mathematics, science, and engineering but also of how these can be related to problems people face every day. Kimmel et al. asserts that this practical mode of inquiry creates further meaning for the learners [33]. Participating teachers intend to bring what they experienced as learners in the RET to the students in their classrooms in the future. The teachers reflected that seeing those connections firsthand brought an increased awareness on one hand and on the other these experiences prepared them to better guide their students in the process of establishing those connections themselves.

Participants reflected on their improved understanding and gains in content knowledge related to mathematics, science, and engineering. In order to gauge the incoming content level of participants, two tests were administered at the beginning of each summer program. Teachers completed a Force Concept Inventory test and a Calculus Readiness Assessment to estimate their content knowledge in physics and mathematics. In 2011 and 2012 a third content test, AP Chemistry, also was administered (see Tables 4, 5, and 6).

Table 4. Force Concept Inventory Scores for All Participant and Content Subgroups.

Content Area	Mean (SD)	Frequency
All Teachers	.39 (.24)	28*
Science	.37 (.14)	15
Physics	.90 (.03)	3
Mathematics	.27 (14)	10

*Note: Numbers sum to 28 rather than 23 because 5 participants attended two consecutive years.

Table 5. Calculus Readiness Assessment Scores for All Participant and Content Subgroups.

Content Area	Mean (SD)	Frequency
All Teachers	.73 (.25)	28
Mathematics	.91 (.11)	11
Science	.60 (.24)	17

Table 6. AP Chemistry Test Scores for All Participants and Content Subgroups.

Content Area	Mean (SD)	Frequency
All Teachers	.49 (.23)	16*
Mathematics	.29 (.13)	5
Science	.58 (.20)	11

*Note: This test was administered years 2 and 3 of the RET; One teacher attended both years.

As evident from the results, for every test the teachers who taught the specific content of the test outperformed their fellow teachers. For example, the physics teachers performed much better on the Force Concept Inventory (M=.90, SD=.03) in comparison to the other science teachers who scored .37 (SD=.14) and the mathematics teachers who scored .27 with a standard deviation of .14. The Calculus Readiness Assessment average for all the participants was relatively high

(M=.73, SD=.25). Nevertheless, the mathematics teachers performed better on that test (M=.91, SD=.11) than teachers who taught in areas other than mathematics. The science teachers had better background knowledge in chemistry as evident by their mean score of .58 and a standard deviation of .20 in comparison to the mathematics teachers whose mean score was .29 and a standard deviation of .13.

These differences in content knowledge were likely associated with the teachers' limited exposure to content beyond their specialization in pre-service and in-service trainings. The teachers came from different areas (mathematics and science) and it was reasonable to assume that the mathematics teachers may be lacking knowledge in certain science areas while the science teachers might not have had the opportunity to be exposed to a wide range of mathematics concepts. However, as evident from their reflections and interviews, the RET allowed them to gain exposure to a variety of other content areas. The participants reflected on their improved understanding and knowledge expansion across areas of mathematics, science, and engineering content, as well as in real-world applications to societally relevant energy and environmental issues.

Participating teachers received this content in multiple modes. They were exposed to different concepts while working in the research laboratories as well as during their design activities. In addition, they attended a number of lectures both in the US and in the UK. All of these different venues allowed participants to gain both theoretical and practical knowledge about a number of concepts relative to all three areas: mathematics, science, and engineering. One teacher shared his perceptions of the greatest benefit of the program when he said, "as a teacher, for [him] the most important part was being exposed to content". A number of specific content concepts appeared in the participants' responses. These included the structure and functioning of fuel cells as one teacher described, "I learned a lot more about fuel cells obviously and that there are a tremendous number of fuel cells and different fuel cells can be used for different purposes." Another area that the teachers had limited experience with prior to RET was hydrogen energy and hydrolysis. However, at the end of the program a number of them had achieved a better understanding and appreciation for their applications. Some of the comments included, "I learned a lot about like hydrogen energy like I had no idea how it worked" while another teacher elaborated on what he learned, "I definitely gained a better understanding of hydrogen energy from that conference and how the engine works." This new knowledge was motivating for the teachers and they took initiative to independently seek out more information about these issues. One participant admitted that "[she] had to go home and find out a whole lot more about LEDs to understand what [she] was doing." The new knowledge and practice that the participants gained during the RET also boosted their confidence in their own understanding as one teacher admitted, "You know giving and providing that lecture time is definitely boosting the teachers' confidence in that subject that they're not very familiar in." In the overall reflection of the six-week experience, the participants shared their transformation through their own eyes.

> I have definitely been exposed to the need to incorporate more science concepts into my classroom. Before RET, I viewed science and mathematics as related, but I wasn't very concerned with that relationship. The lines [differences] between mathematics and science are definitely blurred for me now. I see that as a mathematics teacher, I am also a science teacher, and vice versa.

The newly developed content knowledge affected participants personally and improved their confidence that they could bring those concepts into their classrooms. The content knowledge was directly linked to implementation in the classroom through PBL units and other individual projects teachers planned on implementing. Rather than avoiding areas that they did not feel as comfortable with before [35], now they were empowered by their new understanding. Participants expressed their readiness to take the initiative and teach their students about those new and exciting concepts. Garet et al. [41] described content knowledge as one essential feature of an effective professional development initiative. As RET teachers gained greater proficiency in their own content area and developed further expertise in their complementary one, they became better prepared to adequately bring both of these content knowledge areas into their classroom. The better preparation as perceived by the teachers themselves increased their comfort and confidence in engaging their students in effective mathematics and science learning.

Conclusion

Our findings focus primarily on the impact of the RET on participating teachers. Our evidence from teacher self-report and limited observation indicates that students were more engaged and enthusiastic when working on problem-based learning activities. However, this is relatively anecdotal evidence and more controlled study of the impact on student learning and motivation is needed. Assessing the impact that incorporating engineering into the curriculum has on student learning in mathematics and science is difficult. More research needs to be done to develop new means of assessing this impact [35]. The lack of definitive data on the impact of programs like ours is not limited to engineering and can be found in several areas [42].

Participating teacher impacts on cultural awareness and problem-based learning (see Figure 3), and to a lesser degree content knowledge and mathematics-science connections, were directly related to novel elements of this RET. Exploration of the impact that the international component and our strong emphasis on pedagogical support for PBL and engineering design had on participating teachers is a clear contribution to existing literature on RET projects. It is our hope that similar components will be encouraged for funding in future RETs.

Overall feedback about the program was overwhelmingly positive. RET teachers expressed their appreciation for the different components and their integration in a single professional development experience. The fact that there were a set of different foci was considered an advantage, "This program has more components to it than most programs." Participants commented on the value of each individual component. Many of the teachers valued the research experience as an opportunity to engage and get immersed fully in their project, "it's stuff that it's actually enjoyable because we're actually doing it ourselves." The time allocated for development of PBL units and social relationships participants built with program personnel and each other were essential. Participants collaborated with other teachers, advanced graduate students, and university faculty; they shared ideas and received immediate feedback, "the working relationship has been really good and the ability to share a lot of ideas has been really good." The teachers' exchange of ideas allowed participants with less experience to learn from those who have been teaching longer as well as from their mentors in the research labs. One participant elaborated on the value of this opportunity, "They're like the best of the best. I honestly think that like every single question we've had they've tried to answer it." This collaborative environment went beyond the RET program as some of the teachers left with plans for working together during the following academic year through projects that brought their classrooms together. Others adopted their fellow teachers' projects in addition to creating new units for their own classrooms and thus graduated the RET with better preparation for the following year. The level of engagement was another significant strength as one teacher noted, "This has been one of the best workshops that I've ever been at. It's been very good as far as being able to work with people and the relationships with the teachers and with the professors, both here and in the [United Kingdom]."

Despite the positive feedback from participants over the three years of this project, teachers also shared their thoughts about ways to improve the project. There were two main areas that were identified as potential aspects of improvement in their recommendations. While these issues were partially addressed with later cohorts, some room for improvement remained throughout. The first area was related to the structure on this experience. Many teachers felt that the international experience provided them with a pool of ideas that they incorporated in their PBL units. For this reason they believed that moving this experience earlier in the project would be very beneficial to them. Within the international experience, many teachers expressed their wishes to have the opportunity to visit more schools in England. They saw great value in being able to conduct these observations and believed that "a second school visit would have been beneficial." Others wanted to have the flexibility to allocate their time according to the demands of their research activities and the PBL development. That option would allow them to spend additional time in the research labs where they could get involved deeper in the research opportunity or spend more time on preparation of their PBL units when these needed to be completed. Having more specific concrete instructions and deadlines about the PBL unit development was another recommendation. As many teachers felt that each one of them had a different understanding of what PBL is, they felt a uniform set of instructions would have been beneficial for their PBL writing process.

The second area of emphasis for potential improvement was the content of the research labs. A few of the participants shared that they had difficulty seeing connections between the authentic research that they were engaged in and the PBL units that they developed even though they admit that they learned a lot of content through their research experiences. This area of improvement was more prevalent in some research labs compared to others. This was a major concern for a number of the math teachers. They saw a disconnect between the engineering research they were engaged in and their classroom needs when working to develop their PBL unit. They shared that it might be beneficial to receive some materials regarding the research in advance in order to prepare prior to attending the RET. In addition, even though several lectures on different content material were presented to the participants, the teachers recommended more of those lectures be included. This specific component seemed to be valued greatly by the participants in allowing them to expand their knowledge on topics that they could directly implement in their classrooms. The RET was not initially conceived as primarily a content knowledge delivery mechanism, but the intersection of low content knowledge on our metrics and teachers' perceptions that additional content delivery would be helpful led us to recommend greater emphasis on this component in the future.

These recommendations provide insight on what teachers found valuable and beneficial for their practice and professional development. The connectedness across the different elements created a rich experience that impacted all participants on a number of different levels even though they had diverse backgrounds and prior experience. For this reason, there is a strong argument for continuing professional development opportunities such as this incorporating components that address content knowledge across mathematics, science, and engineering on one hand and practical pedagogical tools and skills that can be incorporated in the classroom on the other hand. In addition, full immersion in an authentic research field allowed participants to actively get involved and learn in a manner that they were never engaged in before. These program features identified by this group of teachers as essential should be implemented in the design of future professional development opportunities for teachers in the fields of mathematics, science, and engineering.

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