

# **Living in a Materials World: Materials Science and Engineering Professional Development for K-12 Educators**

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## **AC 2011-2432: LIVING IN A MATERIALS WORLD: MATERIALS SCIENCE ENGINEERING PROFESSIONAL DEVELOPMENT FOR K-12 EDUCATORS**

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Anne Seifert is the Science, Technology, Engineering and Mathematics (STEM) Coordinator for the Idaho National Laboratory (INL) and serves as the INL's Department of Energy Office (DOE) of Science Education Program Manager. She received a BS degree in elementary education with a minor in science and special education from University of Idaho. She completed a MA in Education Administration and an EDS in Educational Leadership at Idaho State University. As a 30 year veteran educator, she served as highly skilled and outstanding elementary school teacher and administrator in Idaho Falls, Idaho and Denver, Colorado. She has been involved as an educational leader in school reform, assessment literacy, student achievement, school improvement, and has served as an advocate for STEM education in Idaho for many years. Anne was a member of a statewide school improvement leadership team sponsored by the Albertson's Foundation and Boise State University. As an advocate for STEM education, Anne works aggressively to address the challenges facing educators as they seek to reform teaching and learning in STEM disciplines. As INL's K-12 STEM Education Coordinator, her work involves coordinating partnerships with educators, the State Department of Education, business, and industry to raise the awareness of the need for quality K-12 STEM Education in an effort to arm students with the necessary skills of the 21st century in preparation for the workforce of tomorrow. She also serves as the i-STEM Executive Director. Anne believes that teachers empowered with right resources and outstanding professional development, can and will positively impact students; inspiring them to advance their studies in STEM areas so that they are prepared to make informed decisions that will positively impact the way they live, how they live, and our nation's resources and security.

## **Living in a Materials World: Materials Science and Engineering Professional Development for K-12 Educators**

### **Abstract**

Advances in materials science are fundamental to technological developments and have broad societal impacts. For example, years of materials science research has gone into developing cellular phones which are composed of polymer cases, liquid crystal displays, LEDs, silicon chips, Ni-Cd batteries, resistors, capacitors, speakers, and microphones, and compacted into a space equivalent to that of a deck of cards. Like many technological developments, cellular phones have become a ubiquitous part of society, and yet most people know little about the materials science associated with their development. The rich context that materials science provides for learning Science, Technology, Engineering, and Math (STEM) content and the need to enhance K-12 educators' knowledge of materials science was the motivation for developing and offering a 20 hour four-day professional development course entitled "Living in a Materials World." In addition to exposing the participating K-12 educators to the fundamentals of materials science, the course provided a means for bridging our every day experiences and the work of scientists and engineers.

"Living in a Materials World" was one of the fifteen STEM content courses offered as part of the Idaho Science, Technology, Engineering, and Math (i-STEM) summer institute for upper elementary and middle school teachers. The four-day institute included a 20 hour course and 12-16 hours of plenary sessions, planning, and collaborative sharing. The goal of the i-STEM institute was to enhance the participating educators' STEM content knowledge, capacity for teaching STEM, comfort and attitudes toward teaching STEM, knowledge of how people learn, and strategies for integrating STEM throughout the curriculum. In addition, the participants received STEM curriculum in materials science and a resource kit composed of STEM materials and equipment, valued at about \$300, to support the implementation of curriculum and content learned at the institute with their students.

The i-STEM summer institute participants were pre/post tested on their comfort with STEM, perceptions of STEM education, pedagogical discontentment, implementations of inquiry, attitudes toward student learning of STEM, and content knowledge associated with the specific course they took during the institute. The results from our research indicate a significant

increase in content knowledge for the Living in a Materials World strand participants ( $t = 11.36, p < .01$ ) (results were similar in the other courses). As a whole the summer institute participants expressed significant increases in their comfort levels for teaching STEM ( $t = 10.94, p < .01$ ), inquiry implementation ( $t = 5.72, p < .01$ ) and efficacy for teaching STEM ( $t = 6.27, p < .01$ ), and a significant decrease in pedagogical discontentment ( $t = -6.26, p < .01$ ).

## **Living in a Materials World**

Everything is made of something, and the things we manufacture or create are typically made from materials that are readily available and optimal for the product or conditions. Through the work of materials science we continue to refine and discover new materials or new uses for existing materials resulting in the development of new and/or higher performing products. Thus, the science and engineering of materials impacts almost all facets of our lives, and yet, materials science is seldom explored outside of universities and research and development labs. However, the fundamental processes of materials science provide an excellent context for engaging K-12 students and teachers in the exploration of a wide range of STEM concepts.

The National Academies' report on engineering education in K-12<sup>1</sup> highlights the benefits of engaging K-12 students in engineering education and the inextricable link between engineering and math and science education. Further, the National Academies' report explores the positive influence of engineering education activities on K-12 students' math and science achievement, building a case for using engineering education as a context for attaining a wide range of academic goals. The potential for using engineering as a context to enhance K-12 teaching and learning provides justification for exploring instructional approaches and researching their effectiveness. This is particularly true for materials science which may be used to explore concepts of chemistry, earth science, physics, biology, mathematics and engineering, and for which there is a dearth of empirical studies reporting its effectiveness as a context for teaching and learning.

It was with consideration of the National Academies report<sup>1</sup> and the lack of reported empirical research on preparing teachers to teach using materials science as a context for teaching STEM that motivated our research. The need for evidence and models prompted us to develop a 20 hour professional development course for teachers of grades 4-9 that used materials science as the context for teaching a range of STEM topics. The course, *Living in a Materials World*, was part of the 4 day i-STEM residential summer institute designed to enhance the participating educators' knowledge and comfort with teaching STEM. To determine the effectiveness of the course, participants were pre and post tested for knowledge of the materials science concepts that were covered. Further, the participants were pre and post tested for comfort levels, conceptions of STEM, perceptions of STEM teaching, and their pedagogical contentment. Our report details the study and outcomes. Prior to exploring our research, we delve into the relevant literature that supports our research.

## **Materials Science in K-12 Education**

The increasing presence of engineering in the K-12 STEM education has amplified the need to prepare K-12 teachers to teach topics within the domain<sup>2</sup>. Initiatives, such as the one reported

by Williams<sup>3</sup> have used extant engineering curriculum to guide the continuing education of teachers and prepare them to teach the related concepts. The topics covered in many of the engineering education teacher professional development efforts span the spectrum of engineering<sup>3,4</sup>. However, for the most part these endeavors have focused on high school teachers or teachers of engineering curriculum. Thus, there is a need to determine if using the context of engineering is effective for preparing a greater diversity of teachers to teach a range of STEM content, enhancing their STEM knowledge, and their perceptions of their STEM pedagogy. Of particular interest, is the effectiveness of using materials science engineering to enhance elementary, middle and junior high teachers' preparation to teach concepts associated with science and mathematics.

In our search of the literature we exposed curriculum or reports of programs that used aspects of materials science for K-12 teacher professional development in engineering (e.g. Norman and colleagues<sup>5</sup>). However, these reports typically limit the presentation of empirical data that document the effectiveness of the programs at enhancing their participants' knowledge of engineering, and not necessarily the influence on the teachers' preparation to teach STEM. Further, in our search of the literature we were unable to locate any investigations that explicitly used materials science to enhance K-8 teacher preparation to teach STEM content. The lack of readily available published investigations reporting empirical data associating professional development using materials science on teacher preparation to teach STEM content provides support for our research. We posited that a well crafted, interactive materials science curriculum would engage the participating teachers in learning the associated concepts and enhance their knowledge and preparation to teach materials science related STEM content and concepts. Although, our course was designed with teachers of grades 4-9 in mind, we structured the curriculum and content to be engaging in to any K-12 teacher. Thus, we assured that the curriculum was adaptable by allowing time for exploration, flexibility in topics explored, and attention toward a variety of instructional strategies which allowed teachers to adopt and adapt their knowledge to a meet the STEM learning needs of a wide spectrum students. Further, our focus on materials science provided the participating K-12 teachers with a context (e.g. using engineering design principles and scientific inquiry to engage students in learning) applicable to teaching a wide range of STEM curriculum and concepts.

## **Teacher Professional Development in STEM**

Most K-8 teacher preparation programs require their graduates to have completed two semesters of math and two semesters of science, leaving them with limited preparation to teach math and science content<sup>6</sup>. A broad understanding of math and science is especially critical for elementary teachers who may be responsible for teaching a range of math and science topics and concepts<sup>7,8</sup>. The potential need to teach a broad range of science and math content and the predicted constrained preparation provide the justification for providing professional development for K-8 teachers focused on enhancing their preparation to teach math and science. Further, the increasing presence of engineering in the K-8 curriculum<sup>1</sup> provides the justification for also attending to these teachers' capacity to teach engineering related content. Thus, the constrained preparation and exposure to STEM content and the likelihood for the need to effectively teach a range of STEM concepts provided additional validation for our creation, implementation, and investigation of a professional development program designed to use materials science to enhance teacher capacity to teach STEM content.



Teacher professional development can have both implicit and explicit goals influencing an assortment of teacher content, pedagogical, and affective variables<sup>9</sup>. The connection between teacher confidence and efficacy with their effectiveness<sup>10, 11</sup> and the possible relationship between content knowledge and teacher effectiveness<sup>12, 13, 14</sup> provides warrant for attending to a wide range of variables in teacher professional development.

We embraced the notion that attention to a wide range of variables is necessary to influence teacher effectiveness, enhance their practice, and continue their education. Thus, we structured our summer institute course to attend to the teachers' affective states in relation to teaching STEM, their STEM content knowledge, and STEM pedagogy. For example, our course explored a wide range of topics from materials science and engineering to make the content relevant and engaging to the teachers in learning in ways that were intended to enhance their capacity and desire to teach an array of STEM content.

## **Our Research**

The goal of this research project was to develop and implement a professional development course for teachers grade 4-9 focused on enhancing their capacity to teach STEM using the context of materials science, scientific inquiry, and engineering design. We sought to model the processes of inquiry and design for teaching STEM through a series of activities that made explicit an array of STEM disciplines. Further, we intended to increase the participating 4-9 teachers' knowledge of the engineering associated with materials science and provide them with ideas for using the associated concepts to teach a range of STEM subjects.

We used the following research questions to guide our investigation:

- *Did the participants' knowledge of materials science change from pre-course to post course?*
- *Did the participants' comfort for teaching STEM, the pedagogical discontentment for teaching STEM, and attitude toward teaching STEM change from pre to post course?*
- *Did the participants' perceptions and ideas for using inquiry to teach STEM change from pre to post course?*
- *How did the participants' evaluate the course?*

We predicted that the participants would experience significant gains in their materials science and related STEM knowledge, in their comfort for teaching STEM, in their pedagogical contentment, and in their attitudes toward teaching STEM. In addition, we predicted that the participants' perceptions and ideas for using inquiry as an instructional approach would increase. Finally, we predicted that the interactive nature of the professional development course would lead to positive perceptions of the experience by the participants.

## **Participants**

The participants in this project were a subset of a larger group of K-12 teachers attending the summer institute. There were a total of 230 participants in the summer institute, 12 of which selected the *Living in a Materials World* course from a menu of 15 courses. Thus, unique to our 12 participants was their self selection of *Living in a Materials World* as their course of choice

and therefore, their inferred interest in materials science. We maintain that the 12 participants were a representative subset of the 230 educators who participated in the summer institute (as we also assert with regard the subsets of educators enrolled in the other 14 courses). However, due to the way we structured our data collection (with a high level of anonymity) we were not able to associate demographics with the participants in the materials science course (or any other subset of participants in the i-STEM summer institute). Thus, we complied with our Institutional Review Board guidelines for collecting demographic data which is structured to minimize the ability to link responses to the individual completing the survey(s).

The 230 participants in our summer institute were on average 42.21 ( $S = 10.69$ ) years old, had been teaching an average of 12.35 ( $S = 9.39$ ) years, and had taken on average 4.28 ( $S = 1.58$ ) college level science classes and an average of 4.01 ( $S = 1.61$ ) college level mathematics classes. Females made up 80% of the participants, while 84.2% participants were from urban or suburban communities. Teachers from K-5 or K-6 schools made up 39% of the participants with middle school teachers representing 28%, and high school teachers representing 7.5%, with the remaining 25.5% coming from K-8, K-12, and alternative schools. The majority (58.9%) of the participants had majored in elementary education, with the remainder holding degrees in various domains, most of which were related to STEM including instructional technology and health education. Data were collected anonymously with teachers supplying the last five digits of any phone number as a unique code which we used to track responses. Therefore, all data analysis and tracking was dependent on the participant using the same code throughout the data collection, which we found did not always take place. Consequently, some of our measures and analysis are inferred from the subset of the institute participants who we were able to track to the population of teachers who attended the summer professional development program.

## Measures

*Demographics.* To assess our participants' professional characteristics we developed a demographics instrument based on the information we determined to be salient to our research questions. Therefore, we included standard items such as age, gender, and ethnicity. In addition we incorporated items assessing the grade level in which our participants taught, their college majors, the configuration of their schools and community setting, and the number of college level math and science course they had completed.

In our demographics survey, we included a single item in which we asked participants to rate their comfort with teaching STEM curriculum on a scale of 1 "Very Uncomfortable" to 10 "Very Comfortable." Items similar to these have been used in prior research and have generated data that were highly correlated with the outcomes from instruments used to measure the same construct or variable with established reliability and validity.<sup>15</sup>

*Pedagogical discontentment.* To assess our participants' pedagogical discontentment for teaching STEM we modified the 21 item Science Teachers' Pedagogical Discontentment Scale (STPDS)<sup>16</sup>. The original instrument was designed to determine the effectiveness of professional development for decreasing teachers' discontentment with teaching science. The STPDS instructs survey takers to rate their level of pedagogical discontentment on a five point Likert scale to statements such as "Teaching science to students of lower ability levels." The

scale ranges from “1” presenting “no discontentment” to “5” representing “very high discontentment.” The STPDS does have six subscales, which can be examined separately or aggregately. We modified the scale by replacing the word “science” with “STEM” to create items such as, “Teaching STEM to students of lower ability levels.” Many of the items, such as “Monitoring student understanding through alternative forms of assessment” required no modification. Southerland and colleagues established the validity of the instrument through interviews with science teachers and feedback from teacher professional development experts. The reliability of the instrument was established to have a .93 Cronbach’s alpha with the subscales Cronbach’s alphas ranging from .77 to .89, which indicates a good to high level of instrument reliability.

*Inquiry implementation.* To assess our participants’ instructional practices with inquiry implementation, we used a modified version of the Inquiry Science Implementation Scale (ISIS) <sup>17</sup>. The original instrument assesses level of inquiry implementation in science using the prompt, “When you teach science, how frequently do you:” to each of the 22 items. The items include statements such as, “demonstrate the use of a new instrument?” and “ask students to make predictions about an experiment?” Survey takers are to rate their perception of their implementation on a five point Likert scale ranging from “1” representing “never” to “5” representing “always” We modified this scale by adjusting the stem prompt to read “When you teach STEM, how frequently do you:” but did not change the questions on the scale. The instrument has established validity and a Cronbach’s alpha reliability of .89 which was verified using samples of inservice teachers.

*Efficacy for teaching STEM.* To assess our participants’ perceptions of their effectiveness for teaching STEM we modified the Science Teaching Efficacy Belief Instrument (STEBI) <sup>18</sup>. The original instrument contains 25 forward and reversed phrased items to assess efficacy for teaching science. Participants rate their beliefs on a five point Likert scale ranging from “1” representing “Strongly Disagree” to “5” representing “Strongly Agree” as they respond to items such as, “I am continually finding better ways to teach science” or reversed phrased items such as, “I am not very effective in monitoring science experiments.” We made modifications to some of the STEBI items to reflect a more general focus on STEM, rewriting items such as, “Increased teacher effort in teaching science produces little change in some student's science achievement” to read “Increased teacher effort in teaching STEM content produces little change in some student's STEM learning achievement.” The modified version of the instrument was previously used to assess elementary level teachers participating in STEM professional development, and achieved an internal reliability alpha of .85 <sup>9</sup> indicating a good level of instrument reliability.

*Knowledge of materials science.* We developed our own knowledge of materials science assessment which was aligned with the Living in a Materials World curriculum. The assessment was composed of 20 free response items. Participants were asked to respond to items such as “Describe the mechanical properties of a ceramic.” and “What is a composite material? Cite one example.” The assessment was designed by a professor of materials science with extensive expertise in teaching and assessing learner knowledge of materials science concepts. The goal for the assessment was to determine the extent to which the participants grasped the fundamentals of materials science as well as applications of the associated



concepts. Scoring was based on the extent to which the response accurately represented the accepted and current perceptions from the perspective of a materials scientist.

*The Living in a Materials World Course.* The *Living in a Materials World* course was part of an intensive four-day residential summer institute. The institute was structured to have about 6 hours of collaborative planning, 6 hours of plenary and panel presentations, about 12 hours for socializing and networking and 20 hours of content/domain specific courses exploring a theme integrating STEM, such as materials science. The courses met for approximately 5 hours per day with the instructional time nearly evenly divided between morning and afternoon sessions. Consistent to all courses was a focus on inquiry, integrating STEM curriculum, integrating the content into the current 4-9 curriculum, STEM pedagogy, using the instructional materials that were introduced in the strands, and assessment of student learning.

Teachers in grades 4-9 and their administrators from across the state were encouraged to apply to be participants in the summer institute, and register as part of learning team. The idea was to establish the participants in professional learning communities that would continue to support the development and implementation of STEM curriculum following the summer institute. This was envisioned as a way to sustain the participants' professional development and engagement in the larger STEM community.

The institute was supported by a grant and funding from Battelle Energy Alliance, and other industry partners which allowed us to cover the costs of meals, lodging, travel, 2 continuing education college credits, a resource kit values around \$300 worth of content strand related materials, and a stipend for all the participants who attended the conference. We also financed the time and expenses of the course instructors and other conference presenters.

The content provided by the institution in the 15 different 20 hour themed STEM courses was dependent on the proposals submitted by STEM content experts included individuals, industry partners, or organizations who applied to be strand providers. It was the responsibility of the individual(s) who proposed the course to develop the course objectives and content. The topics covered in *Living in a Materials World* course included:

- Classification of Materials
- Atomic Structure, the periodic table and bonding
- Crystallography
- Defects
- Diffusion
- Phase Diagrams & Phase Transformations
- Mechanical Properties and Strengthening Metals
- Failure
- Electrical properties
- The Whitewater Kayak
- Biomaterials
- Nanotechnology

These topics were explored in the course through instruction that relied on a combination of the utilization of equipment from the learning kits, lecture, discussion, guided inquiry, laboratory

activities, demonstrations, and computer simulations. Emphasis was placed on exploring how the teachers might integrate these topics into the curriculum, how the hands-on activities may be adapted to teach a range of STEM concepts, and how they might differentiate instructional practices and curriculum to meet the needs of their students.

## Results

We began our analysis by determining the reliability of our instruments. We calculated the Cronbach's alpha for each measure using the pre-test scores ( $N = 229$ ). For the inquiry implementation measure the alpha was .97, for the pedagogical discontentment survey the alpha was .93, for the efficacy for teaching STEM our alpha was .83. We interpreted the reliability scores to be representative of good to high levels of acceptability, indicating we could proceed with our analysis under the assumption that the instruments we used to gather our data performed consistently.

Our first research question asked: *Did the participants' knowledge of materials science change from pre-course to post-course?* To answer this question we examined the pre and post course Living in a Materials World assessments of the participants knowledge. Using a paired samples t-test we revealed a significant increase  $t(11) = 11.35, p < .01$ , with a pre-test mean of 4.17 ( $S = 13.06$ ) and a post –test mean of 14.92 ( $S = 10.63$ ) on the 20 item measure. The results illuminate the substantial increase in the participants' materials science content knowledge.

Our second research question asked: *Did the participants' comfort for teaching STEM, the pedagogical discontentment for teaching STEM, and attitude toward teaching STEM change from pre to post course?* To answer this question we conducted a pre/post analysis of our measure of teacher comfort for teaching STEM, pedagogical discontentment associated with STEM, and efficacy for teaching STEM of all institute participants. We examined all participants because of the statistical power and the fact that several of the Living in a Materials World participants appeared to have used different codes for their content assessments and the general measures of institute outcome. Therefore, we elected to conduct our analysis of all matched pre/post data ( $N = 128$ ) and infer the results to our course participants.

Our repeated measures ANOVA analysis revealed significant increases in our participants' comfort levels for teaching STEM  $t(124) = 10.94, p < .01$ , attitudes toward teaching STEM  $t(124) = 6.27, p < .01$ , and significant decreases in pedagogical discontentment  $t(124) = -6.26, p < .01$ . The shift in means for comfort from 5.62 ( $S = 2.46$ ) to 7.89 ( $S = 1.55$ ) on the 10 point scale reflects an effect size of .49 (partial eta squared). The shift in means for efficacy for teaching STEM from 3.45 ( $S = .35$ ) to 3.67 ( $S = .36$ ) on the five point scale reflects an effect size of .24 (partial eta squared). Finally, the shift in means for pedagogical discontentment from 2.09 ( $S = .63$ ) to 1.78 ( $S = .53$ ) on the five point scale reflects an effect size of .24 (partial eta squared).

Our third research question asked: *Did the participants' perceptions and ideas for using inquiry to teach STEM change from pre to post course?* To answer this question we again conducted the analysis of the data resulting from all institute participants pre/post matched responses to our assessment of inquiry implementation. Our analysis revealed significant increase  $t(124) = 5.72, p < .01$ , with an effect size of .21 (partial eta square) as the mean shifted

from 3.62 ( $S = .82$ ) to a post test value of 4.01 ( $S = .57$ ) on a five point scale. These results indicate that the participants' perceptions and thoughts about implementing inquiry were more positive following the summer institute.

Our final research question asked: *How did the participants' evaluate the course?* To answer this question we examined the outcome from our program evaluation submitted by the participants in the Living in a Materials World course. We were able to track these responses by course because the participants were requested to identify the course by unique code on the valuation forms. Since the evaluations were anonymous the identification of course was not linked to an individual which enhanced the probability of participants providing honest and accurate feedback. Participants responded to the evaluation survey using a seven point Likert scale ranging from 1 representing "strongly disagree" to 7 representing "strongly agree." The mean and standard deviations of the responses for the Living in a Materials World course participants and all institute participants are presented in Table 1 along with the evaluation item themes.

Table 1

*The Evaluation Item Themes and the Mean and Standard Deviations of the Living in a Materials World Participants and Values of All Institute Participants*

Evaluation Theme	Living in a Materials World		All Institute Participants	
	<i>M</i>	<i>S</i>	<i>M</i>	<i>S</i>
Organization & Delivery	4.77	1.15	5.33	1.38
Presenter Knowledge	6.69	.39	6.51	.83
Hands on Activities	5.38	1.14	6.09	1.41
Instructional Materials	5.77	.89	5.68	1.35
Use of Time	4.77	1.29	4.93	1.80
Instructional Kit	6.33	1.49	5.52	1.90
Content Knowledge	6.54	1.00	5.75	1.65
Implementation Comfort	6.15	.87	6.25	.85
Probability of Implementation of Content	6.58	.52	6.27	.97
Recommend to Others	6.08	1.13	5.84	1.68

Using a descriptive approach to the data analysis it appears that for the most part the participants' evaluation of the course was consistent with the evaluations submitted by participants attending other courses. Notable marginal deviations are the outcomes for the organization and delivery of content, hands-on activities, and content knowledge. Regardless, our analysis did not expose substantial variations between the *Living in a Materials World* course evaluations and the evaluations of the other institute courses.

## **Discussion**

The goals of this research project were to enhance the participating grade 4-9 teachers' content knowledge, attitudes, and pedagogy associated with teaching STEM by engaging them in a course focused on materials science. To achieve these goals, we provided an intensive 4day residential summer institute that included 20 hour STEM content course on materials science, *Living in a Materials World*. We then examined the influence of the course on the 12 participants' knowledge of materials science, as well as the inferred influence on their confidence for teaching STEM, pedagogical contentment in relationship to STEM, inquiry implementation for teaching STEM, and STEM teaching efficacy. In addition, we examined the course participants' responses to our program evaluation form to garner additional insight into their perceptions of the course and their propensity to integrate the materials science content into their STEM curriculum.

Our results indicate that the participants in the Materials World course experienced a substantial increase in their materials science content knowledge. The increase, which we attribute to the course content and format of instruction, appeared to also influence their likelihood to implement the content as part of their STEM curriculum (as made evident from the evaluation responses). The rather low pre-test scores for content knowledge suggest that the participants had little or no knowledge of materials science or related STEM concepts (from the perspective of an engineer) prior to the course. In contrast, the post test scores indicate significant increase in understanding of material science and STEM through the lens of engineering. During the Materials World course, the participants engaged in a number of activities that applied engineering design as they explored concepts of materials science, such as the creation of composite rods that they tested for strength. The acquisition of knowledge of an engineering perception of materials science suggest a greater understanding not only of materials science concepts but also the processes (scientific inquiry and engineering design) used in materials science research and development. The increased knowledge of the process, modeled and taught in the course, are effective for exploring a wide range of STEM content, particularly related to the multidisciplinary facets of materials science. Although the hands-on activities were a major component of the class, the participants rated these lower than the institute participants as a whole in the evaluations. We speculate that this is due to the participants' engagement in activities that involved learning content and performing experiments simultaneously which may have amplified their cognitive load as they labored to master the concepts and the associated processes. Although this seems reasonable based on interactions with the participants further investigation would be required to determine the validity of our explanation. Determining the impressions of hands-on activities and their association with learning by teachers receiving professional development in materials science is an excellent direction for future research.

Our inferred significant results for increases in comfort teaching STEM, implementation of inquiry, efficacy for teaching STEM and pedagogical contentment indicating the educators experienced enhanced affective states in relation to teaching STEM and their perceptions of their STEM instructional practice. Although, the limitations of inferring these outcomes of the entire institute population to our Materials World course study sample are recognized, there was consistency in the structure of the institute for all participants as well as the format and goals of the courses (e.g. emphasis on inquiry and classroom applications). Given the consistencies in institute and course emphasis and structure, we posit the perceptions of the course participants would have been relatively the same for the participants attending any of the institute courses. Further, the consistent expectations of inquiry instruction and emphasis on integrating STEM content was expected in all courses and a focus of the plenary sessions, elements that we assesses in our affective and pedagogy measures. Therefore, given the consistency in the evaluations for our course with the other course evaluations, we maintain the outcomes were likely consistent with the larger population.

Given the justified inference we speculate that the nature of the explorations that took place in the Materials World course, the inquiry and design structure, the presentations of content, the access to materials, and discussions, all contributed to a positive learning experience for the participants. The positive learning experience in turn influenced their comfort for teaching STEM, the efficacy for teaching STEM, their pedagogical discontentment associated with STEM, and their inquiry implementation. These are critical considerations because they all can potentially influence teachers practice and effectiveness for teaching STEM.

One of the primary goals of this research project was to determine if a professional development course that focused on materials science could increase teachers' preparation to teach STEM concepts. We maintain that a well structured course in materials science would enhance the participants' attitudes, content knowledge, and pedagogy for teaching STEM. Our results indicate that the course was effective at achieving this goal, and that materials science can be an effective context for increasing 4-9 teachers' preparation to teach STEM content.

## **Limitations**

Perhaps the greatest limitation to our study was the lack of the ability to track our course participants' scores, beyond their materials science content knowledge, pre to post institute. This was an issue beyond the Living in a Materials World course, as we could not track the responses of about 40% of the participants because they did not attempt all surveys, used different codes pre and post, and left some surveys incomplete. However, our examination of the evaluation data indicated fairly consistent responses to the larger group which suggests that the affective and pedagogical measures and the significant changes are likely to be consistent as well.

Another limitation of our research was the our relatively small samples size, as there were 12 participants in the course. Although we were able to detect substantial impact of the materials science course on their content knowledge, a larger or more diverse population may have performed differently. Therefore, it is difficult to infer our results to a broad range of K-12 educators. However, the impact that we detected and evaluation outcomes are encouraging and



indicate that the course is appropriate and effective for increasing the participants' knowledge of materials science and further preparation to teach a range of STEM content.

The final evident limitation of our research is the self report nature of the data collected. Although the content knowledge assessment was effective for collecting accurate data representative of the participants' understanding of materials science, our other measures of STEM teaching attitudes and practices (comfort, efficacy, pedagogical discontentment, and inquiry implementation) relied more on the perceptions and state of mind of the participants. The dynamic and situational nature of affective states should be taken into consideration when interpreting our results. The collection of these data using a delayed post design may reveal different results and is an excellent direction for future research. Further, how the teachers internalize and apply their knowledge in practice is likely to be a very fruitful direction for further investigation.

## **Conclusion**

Materials science is an excellent example of an engineering field that requires the understanding and application of content from multiple STEM disciplines. Due to the nature of materials science and its applicability to every day experiences it is an ideal context for enhancing teacher capacity to teach STEM content and making STEM content relevant for their students. Teacher professional development courses in materials science that combine STEM content with activities that engage participants in scientific inquiry and engineering design provide teachers with a model that can be transferred to a range of STEM learning contexts. The empirical evidence gathered in our research project indicates that such a course using materials science as a context for teacher professional development is effective for increasing content knowledge of materials science while enhancing the affective states and teaching perceptions of the participating K-12 educators. The success of our course provides further justification for using materials science for enhancing teacher preparation to teach STEM by increasing their STEM knowledge and excitement for teaching STEM content, and leveraging the benefits of life in a materials world.

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