Implementation of Materials Science in the High School Classroom

Dr. Alison K. Polasik, The Ohio State University
Prof. Glenn S. Daehn, The Ohio State University
Michelle R. McCombs, The Ohio State University

Michelle R. McCombs is the Program Manager and Education and Outreach Coordinator for the Center for Emergent Materials, an NSF MRSEC, CEM, at The Ohio State University. She received both her B.S. and M.S. in Chemistry at Western Kentucky University and M.A. in Science Education at the University of California, Davis. In addition to conducting evaluation for this Math and Science Partnership Program, she has led a range of education efforts for CEM including working with undergraduate and graduate STEM students to teach science lessons to inner city elementary students in Columbus, OH; organizing on-campus outreach efforts for middle school students; coordinating a summer Research Experience for Undergraduates (REU) program and organizing professional development experiences for graduate students and postdoctoral researchers. Prior to joining CEM, she worked at the University of California, Davis for a NSF funded Science and Technology Center, the Center for Biophotonics Science and Technology, where she led a variety of similar efforts.
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High school science teachers often express two key challenges: teaching science in a way that encourages students to pursue careers in STEM (science, technology, engineering, and mathematics) fields and equipping graduates with literacy in math and science required for success in those fields. This paper describes a professional development program rooted in the field of materials science that was developed to address these difficulties. The program is funded by the U.S. Department of Education’s Math and Science Partnerships (MSP) program. Over the three-year introductory phase of the program beginning in summer of 2012 and continuing through spring of 2015, several key goals were achieved and the foundation was laid for a further phase of expansion and detailed research into student gains.

Introduction

There is a variety of professional development programs designed to promote interest in STEM fields and to give educators valuable teaching tools. As an example, the ASM Materials Education Foundation (ASM) has offered week-long summer camps to introduce elementary (grade 5 and above) and high school teachers to materials science through hands-on activities and experiments [1, 2]. Materials science is attractive because it is a very accessible and hands-on science and can act as a unifier in typically disjointed physical science courses. While these camps successfully give educators many valuable tools, they are not designed to provide sustained and deep support for teachers to make sweeping changes in pedagogy or curriculum or develop a significantly deeper understanding of related content.

The professional development program described in this paper sought to build on the success of the ASM summer camps by developing a more rigorous year-long teacher professional development program. This program, titled Professional Development for Materials Science-Focused High School Courses, was developed to incorporate aspects of high-quality and effective teacher PD that have been identified within several reviews of educational research, such as: [3-6]

- Relevant content provided by experts that also emphasizes teacher discretion
- Sufficient contact time, and preferably spaced out over time
- Follow up, particularly in the teacher’s classroom
- Activities instead of lectures

This intervention intended increase the content knowledge of teachers, specifically with respect to materials science, and to improve teachers’ effectiveness in teaching science in an interactive and inquiry-based manner. The goals then feed into larger societal goals of increasing the student achievement in STEM. Ultimately, it is believed that improving student efficacy in STEM courses in high school will increase the number of high school graduates who pursue technical careers at all educational levels, increasing the diversity in STEM fields, and increasing scientific literacy and interest in the community at large. While lofty, these goals are reachable when teachers are enabled to effectively educate and engage their students.

Program Description
The objective of the first stage of the program was to design a robust series of professional activities and iteratively hone in on the most worthwhile tools with which to equip teachers. In order to achieve this objective, the program engaged high school teachers, and included between 20 and 30 participants in each of three years between the summer of 2012 and spring of 2015. This initial goals (years 1-3) were therefore to: educate the teachers, build a professional learning community, and promote materials science both as a component of effective courses and a high school elective course as shown in the following figure.

![Theoretical Model for Materials Science Program](image)

Figure 1: Theoretical Model for Materials Science Program. Note that the italicized outcomes are not measured in stage one (academic years 1 – 3), and are not discussed in this paper.

The program year begins in July with a week-long ASM camp. In addition to the 40-hour intensive summer camp, the program incorporates the following components:

**Online Graduate Course**
During one semester each year, the teachers take a two graduate semester-hour course online that covers the fundamentals of materials science. This component incorporates depth in the subject in a way that is adaptable to each teacher’s current knowledge and needs.

**Classroom Support**
An experienced high school materials science teacher visits each teacher four times throughout the academic year to give support with teaching and experimental methods. Guskey and Yoon note that “educators at all levels need just-in-time, job-embedded assistance as they struggle to adapt new curricula and new instructional practices to their unique classroom contexts”[3]

**Full Group Meetings**
These meetings were held four times throughout the year, and a new materials science topic and classroom laboratory was introduced at each one. Time was also allotted for the teachers to share experiences, strategies, and pedagogical best practices with each other. Spending over 70 hours together between the camp and full-day sessions throughout the academic year catalyzed the formation of an informal peer learning community that leads to sustained improvement and evolution.
By delivering intervention and education to the teachers regularly and in multiple ways, the program was naturally iterative and evolutionary. The teachers were consistently getting feedback from students and other peer teachers on the success (or lack thereof) of each activity implemented in the classroom, which was then shared with the program coordinators. The following tools were administered at the beginning and end of each academic year to assess the summative effectiveness of the different activities and measure progress towards goals, in particular the goals related to teachers’ effectiveness in teaching science in an interactive an inquiry-based manner.

**Materials Science Concept Inventory**
A short (22 – 30 question) college-based concept inventory was given to the teachers at the start of the summer camp, the end of the summer camp, and the end of the academic year. This test was used to gauge teachers’ content knowledge of materials science concepts, and included some questions from the physical science and math concept inventories.

**Activity Checklist**
The teachers reported the activities they enacted in their classrooms throughout the academic year as well as the effectiveness of each activity. In-depth discussions with the teachers and surveys given at each meeting provided anecdotal evidence related to the relative merit of each activity.

**Teacher Surveys from Group Sessions**
Detailed feedback was gathered for each of the group sessions and summer camp experiences. Because meetings were frequent, this feedback facilitated consensus on best practice and enabled agile and timely adjustments by program coordinators.

Despite the relatively small number of program participants, the non-experimental evaluation method provided a great deal of valuable information that allowed coordinators to qualitatively assess the value of the professional development programs and improve the program.

**Results**

Over three years, 43 high school teachers participated in the program. Six were participants for two or more years, and ten of the teachers are in the fourth year as of AY 15-16.

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<tr>
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<tbody>
<tr>
<td># Participants</td>
<td>23</td>
<td>27</td>
<td>20</td>
</tr>
<tr>
<td># Returning</td>
<td>–</td>
<td>17</td>
<td>14</td>
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<tr>
<td># 2+ years</td>
<td>–</td>
<td>17</td>
<td>6</td>
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*Figure 2: Table with an overview of teacher demographics*

The continuing interest of teachers in the program is one of the hallmarks of its success, and significant support from the ASM foundation has factored heavily into this. The most passionate of the teachers participating have been able to pursue additional levels of expertise and certification outside of our program through ASM. While this program does not explicitly use a train-the-trainer approach in developing the teachers’ skills, it is interesting to note that this has
evolved of its own within a cohort of teachers who have been a part of each year’s activities. Several of these teachers are in training to become master teachers for ASM camps around the country.

**Teacher confidence and self-efficacy**

The support provided by this program has given teachers the experience, tools, and courage to move from lecturing and assigning worksheets to facilitating discussions and introducing students to complicated and fascinating aspects of science and engineering in an interactive way. The chart below shows that the overall number of activities teachers implemented in their classrooms increased dramatically year-to-year. Surveys given by the teachers in the 2012-2013 academic year indicated that a number of activities teachers were initially interested in were not implemented because of safety concerns. We tracked these “scary activities”, which typically used a blowtorch or acid, and found that the number of these activities increased dramatically as well. This was particularly interesting because conversations with teachers affirmed that these activities tended to draw the greatest interest from students.

![ACTIVITIES BY PROGRAM YEAR](chart.png)

*Figure 3: Self-Reported In-Class activities used by teachers in each program year, by category.*

**Teacher content knowledge**

Despite the extensive amount of intervention, there was only slight evidence to confirm that teachers’ knowledge of key materials science concepts improved. In the first year of the program (AY 12-13), slight gains were shown to occur at camp, and these were maintained throughout the school year. In years 2 and 3, no meaningful gains or losses in understanding were observed for the group at large using the concept inventory.
Figure 4: Average scores on materials science concept inventory for teachers participating in the program during AY 2012 - 13. Note that significant gains were achieved in content knowledge, which was mostly maintained until the end of the academic year.

Change in 18 individual teachers’ scores from before camp to end of the ’13 – ’14 academic year

Average score on Materials Science concept inventory from before camp to end of the ’14 – ’15 academic year

Figure 5: Teacher performance on concept inventories from the beginning to the end of the program year for AY 13-14 and AY 14-15 (program years 2 and 3). This data indicates that there was less significant improvement in teachers’ content knowledge during the second and third years of the program.

It is difficult to pinpoint why the extensive amount of intervention did not appear to result in knowledge gains for the teachers, but two possible explanations stand out. First, the teachers are initially most excited to learn the mechanics of how to incorporate hands-on activities in their classrooms and may not take full advantage of the presentations and material provided to shore up their background knowledge. Second, the measurement tool was ill-suited to its purpose. The Materials Concept inventory used was initially designed for College students in their first or second year of advanced science curriculum, and was intended to measure gains for students entering and exiting an introductory materials science course at that level. As such, we believe that is not effectively calibrated to measure improvement of either teachers or students, whose background knowledge of physics, chemistry, and math together is typically less deep. As the project transitions to incorporating more rigorous research and analysis of student gains using a quasi-experimental method, a more specialized tool is being designed.
Conclusion

While difficult to quantify, a great deal of anecdotal evidence indicates that several key goals of the program were achieved.

- Teachers were empowered to improve their pedagogy.
- The overall experience of students in the classrooms was more positive and students show an increased interest in science. Many teachers expressed that they were surprised by the level at which students were able and willing to respond during open-ended and inquiry-based activities. Several of our teachers work at schools with an extremely transient and traditionally “difficult” student population. These teachers in particular saw some of the most dramatic improvements in student engagement and performance, which they attributed to the real-word nature of many of the activities and concepts they were able to incorporate.
- A dynamic learning community for materials science has been established among teachers in central Ohio.
- Partnership with vocational & technical career centers have been surprisingly rich. As these teachers are able to identify and equip more technically savvy students, we have been able to offer support and information to help direct these students to further training at all levels. In fact, several teachers at technical career centers have joined the program as participants, consultants, or simply engaging informally with other materials science teachers in the program.

This program meets many of the characteristics of professional development that are known to be effective, and has produced a vibrant learning community and improved teacher self-efficacy within the program’s participants. This model builds on the basic ASM camp that is offered nationwide during the summer, and thus is promising in terms of its potential for replication. and the future of the program will focus on assessing whether the gains we have seen in teacher efficacy, excitement, and know-how do in fact lead to gains in student achievement across the board.

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References

