GK-12 Learning Partnerships: An Outreach Program in Engineering Education

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Abstract — *This paper describes the design of the GK-12 Learning Partnership project and the assessment results from the first year of implementation. "GK-12 Learning Partnerships" is funded by the National Science Foundation for three years and has created collaborative teams that include a middle school mathematics or science teacher, a graduate student and a senior undergraduate student. These teams work together throughout the academic year to implement hands-on engineering activities in science and mathematics classrooms. The graduate and undergraduate students have been selected from three academic departments at the Colorado School of Mines: Mathematical and Computer Sciences, Engineering, and Geo-Physics. The first year of the project was the academic year 2003-2004. During this time period, seven graduate students assisted middle school mathematics and science teachers in the classroom for 10 to 15 hours each week. Three undergraduate students provided additional assistance in the classroom for five hours each week from January, 2004, to May, 2004. The implementation of this project has been guided by four goals which take into consideration the impact of project activities on the participating teachers, and graduate, undergraduate and middle school students. Methods of assessment include observations, pre and post tests, focus group activities, questionnaires and standardized assessments. As is discussed in this paper, assessment results suggest that the project is progressing toward the attainment of the intended goals.*

Index Terms — *Assessment, Engineering, Mathematics, Outreach, Science*

INTRODUCTION

Several well-respected groups (e.g., National Council of Teachers of Mathematics, National Education Knowledge Industry Association, National Science Teachers' Association, and the United States Department of Education) have raised concerns about the low level of scientific and mathematical literacy that exists in the United States society and schools. Many of these concerns are based on results from national and international standardized achievement tests. For example, the Third International Mathematics and Science Study found that U.S. students are being outperformed by other nations' students in both science and mathematics [1]-[2]. Results from the National Assessment of Educational Progress (NAEP) suggest that U.S. students from low-income families are performing below their middle class peers in these same subjects [3]-[4]. These findings and concerns that they raise have resulted in a broad range of reform activities that are designed to improve the education that all students receive in mathematics and science in elementary, middle school and high school (e.g., [5]-[9]). Additionally, teaching and learning standards have been developed in both science [10]-[12] and mathematics [13]-[18], as a foundation to support the reform process.

At the very heart of the reform effort lies the belief that student learning occurs through exploration and problem solving. According to the American Association for the Advancement of Science (AAAS) [19], science instruction should include active hands-on exploratory activities that are interdisciplinary in nature. The National Science Board [2] has criticized currently available curricular materials in the following manner, "Few [curriculum materials] introduce real-world interdisciplinary problems and serve as the foundation for advanced placement courses, school-to-work transition courses, or the challenges of a liberal arts college education. Most innovative science curricula, for instance, seek coherence, integration, and movement from concrete ideas to abstract concepts. Unfortunately, traditional teacher education has not prepared teachers to design instruction in a manner that is consistent with these goals." Others have echoed these same concerns [20]-[21].

Another concern is the appropriateness of the level of discipline specific knowledge of practicing teachers. Evidence suggests that both elementary and secondary mathematics teachers' content knowledge is often incomplete and/or fragmented

[22]-[26]. Similar concerns have been raised with regard to science. Moore [27] surveyed 300 secondary science teachers and found that 91% were concerned with their lack of meaningful science courses during teacher preparation. Adding to this problem is the large number of teachers who are providing instruction in a field other than the field in which they were certified. During the 1993-94 school year, Ingersoll [28] found that 27% of mathematics and 18% of science public school teachers were not certified within the field that they taught. Teachers who are teaching outside of their fields are unlikely to have the conceptual knowledge necessary to create problem centered, interdisciplinary learning environments [29]-[29]. Furthermore, the majority of practicing teachers completed their teacher preparation courses long before the current reform began. According to Kirwan [20], the average teacher in the U.S. has been out of school for more than 20 years. These teachers as well as their less experienced peers need to be equipped with new, relevant examples of science and technology in society.

The GK-12 Learning Partnership program is a collaborative effort between the Colorado School of Mines and Adams County School District Fifty. This project is partially funded by the National Science Foundation (NSF, DGE-0231611) and is designed to address the concerns described above. The project has a three year duration and began in August, 2003. The project started with seven graduate students and seven science or mathematics middle school teachers attending an eight day summer workshop. This workshop was designed to increase the teachers' knowledge and understanding of the applications of mathematics to science and engineering through hands-on experiences and to prepare the participating graduate students for the classroom. By the end of the workshop, each graduate student was paired with a teacher to form an instructional team. These teams worked together throughout the academic year to implement hands-on instruction in the middle school classroom. An undergraduate student joined three of these teams in January, 2004, and provided five hours of classroom assistance until May, 2004. The graduate and undergraduate students will be referred to jointly as "teaching fellows" and have been drawn from the following three academic departments: Mathematical and Computer Sciences, Engineering, and Geophysics. The purpose of this paper is to describe the design of the GK-12 Learning Partnership program and report the assessment results from the first year of implementation.

GOALS AND OBJECTIVES

In order to guide the development and design of this project, a statement of goals is necessary. The specific goals of the GK-12 Learning Partnership program are:

1. To foster the cooperative efforts of a practicing teacher, university faculty, a graduate student and undergraduate student in the implementation of problem centered, interdisciplinary learning environments that focus on the application of mathematics to earth science and engineering for middle school students;
2. To enrich the teacher preparation experiences of undergraduate and graduate students who are interested in pursuing pre-college or college education as a potential career;
3. To enrich the content, application and interdisciplinary knowledge of practicing science and mathematics teachers with respect to the application of mathematics to earth science and engineering, and;
4. To enrich the learning experience of middle school students by creating problem centered, interdisciplinary learning environments that focus on the application of mathematics to earth science and engineering.

PROJECT DESIGN

There are several activities designed to support the success of this program throughout the academic year. These include summer workshops, fellowship workshops, and fellowship classroom participation. Each academic year begins with both the teachers and the graduate teaching fellows attending an eight day summer workshop. After this workshop, the graduate teaching fellows assist the middle school teachers, defined here as 6^{th} through 8^{th} grade teachers, in the classroom and attend a fellowship workshop every two weeks. In January, undergraduate teaching fellows are selected and join the instructional teams. These activities are described in detail for the academic year 2003-2004 in the sections that follow.

Summer Workshops

An eight day summer workshop that focused on the applications of mathematics to science and engineering was held in August, 2003. This workshop was attended by seven middle school science and mathematics teachers and seven graduate teaching fellows. A second workshop was held in 2004, was attended by eight middle school science and mathematics teachers and eight graduate students, and focused on the various fields of engineering. In 2005, the third workshop will address earth systems. The summer workshops are eight hours per day for eight days and are taught by faculty members who are experts in the appropriate fields. Since this paper concerns the results of the first year of the project, only the first workshop will be discussed in more detail.

The first five days of the 2003 summer workshop was dedicated to providing the participating teachers with the opportunity to learn scientific and mathematical content through hands-on activities. This type of learning experience is consistent with the local and national standards in science and mathematics (see [10]-[12], [15]-[18]). During the final three days of the workshop, instructional teams were created that consisted of a graduate teaching fellow and a participating teacher. The CSM faculty members who led the first five days of the workshop were also available to consult with these teams. The teams worked to redesign the materials that were presented during the first week of the workshop in a manner that was appropriate to the middle school classroom.

Fellowship Workshops

Throughout the academic year, the teaching fellows attended regularly scheduled fellowship workshops that took place at the end of the school day. A high school teacher who was hired to act as a liaison between the project and the school district scheduled and led these workshops. These workshops ranged from 1 hour to 2 hours in length and took place every two weeks of the academic year. The purpose of these workshops was to strengthen the participating fellows' understanding of the concept of Standards-Based Education and the development of hands-on learning activities. These workshops have a seminar structure in which the teaching fellows are encouraged to share the successes and failures that they experience in the classroom.

Classroom Participation of Graduate Teaching Fellows

Each graduate teaching fellow provided at least ten hours of in-class assistance to participating teachers each week throughout the academic year. This time was used for the following activities: 1) assist teams of students in completing hands-on projects, 2) develop new ideas for hands-on student experiments, 3) individually assist a given student or group of students and 4) provide presentations to the middle school classes concerning what engineers and scientists do. The graduate teaching fellows assisted in the same classes throughout the term. This provided the fellows with insight into the structure of the class and the students taking the class. Three to five additional hours each week were scheduled for the following activities: 1) assist in scoring student assessment activities, 2) attend school related meetings and workshops, 3) maintain a project related web site and 4) provide support to other teachers at the given school.

Classroom Participation of Undergraduate Teaching Fellows

Three undergraduate teaching fellows were selected and joined the instructional teams in January, 2004, and remained in the classrooms until May, 2004. Undergraduates were not included at the start of the academic year because it was felt that introducing both an undergraduate and graduate fellow to a given classroom in August would overwhelm the participating teachers. Due to the demanding academic schedules of undergraduate students at CSM, undergraduate fellows devoted a maximum of five hours to the middle school classroom each week. During this time, undergraduate fellows assisted in instruction, graded student papers or provided one-on-one tutoring to students. Instructional teams that wanted an undergraduate fellow to join their team submitted a proposal in December that described the role that the undergraduate would serve in their classroom. These proposals were reviewed by the Principal Investigator and only the proposals that promised the best experience to the undergraduate fellow were assigned an undergraduate fellow during the spring semester.

ASSESSMENT METHODS

Both formative and summative evaluations were completed throughout the initial year of this project. Since the purpose of this paper is to examine the success of the project with respect to the stated goals, the discussion that follows focuses primarily on the summative evaluation.

Participants

Seven teachers from three middle schools within the Adams County District Fifty participated in the first year of this project. Three of the teachers taught mathematics and four of the teachers taught science. Seven graduate teaching fellows also participated in this project. The majors of the graduate fellows were as follows: 2 Computer Science, 1 Mathematics, 1 Statistics, 1 Engineering and 2 Geophysics. All seven of the graduate fellows were working on Master degrees. Four of the graduate teaching fellows were female and three were male. Three undergraduate teaching fellows joined this project in January, 2004. Two of the undergraduate students were Engineering majors and one was a Geophysics major. All of the undergraduate fellows were in their senior year. Two of the undergraduate fellows were female and one was male.

The first summer workshop was taught by two faculty members from CSM and a high school teacher from Adams County District Fifty. One of the faculty members from CSM teaches mathematics and the other engineering. The teacher from Adams County District 50 is a high school science instructor who has repeatedly been recognized for excellence in teaching.

Workshop Observations and Participant Comments

The external evaluator completed unannounced observations of the first year's summer workshop. During these observations, she sought to evaluate the extent to which each of the project goals were being met through the workshop activities. Approximately every three days during the summer workshops, both the teachers and the graduate fellows were asked to provide their written suggestions concerning what the workshop instructors should keep doing, quit doing and start doing in order to improve their learning. These cards were summarized by the evaluator and used by the workshop instructors for improvement purposes. The project evaluator also attended several of the fellowship workshops during the school year. As will be discussed, focus groups were used as another assessment method during the fellowship workshops.

Pre and Post Tests

At the beginning and end of the first summer workshop, the participating teachers completed a pre and post multiple choice content assessment. This instrument was designed to measure the change in teachers' knowledge with respect to the material presented during the summer workshop. The content experts who taught the summer workshop worked directly with the evaluator in the development and design of the pre and post content assessment. This test was constructed following the guidelines for constructing a multiple choice assessment.

Focus Groups

As was discussed above, the teaching fellows attended fellowship workshops throughout the academic year. During two of these workshops, the external evaluator completed focus groups with the fellows. The first focus group took place in January, 2004, before the new semester began, and, since the undergraduate fellows had not yet joined the instructional teams, consisted only of graduate teaching fellows. The second focus group was completed in May, 2004, at the end of the spring semester. During the second focus group, the students were separated into groups consisting of undergraduate fellows and graduate fellows. The external evaluator led a discussion concerning the classroom and experiences of the teaching fellows. The questions that were asked during these focus group activities are listed below.

1. To what extent do you feel you are active contributors to the team effort?
2. To what extent do you feel you are effectively implementing instruction and assessment that is consistent with the project goals?

For each of the focus group questions, the external evaluator asked the students to provide examples. She then displayed the fellows' responses using a projector. The fellows had the opportunity to review their responses and ensure that they accurately reflected their opinions. Feedback was also acquired from students to ensure that diverse opinions were fairly represented. Additionally, the evaluator reviewed the project goals with the students prior to asking the second focus group question.

Questionnaires

At the end of each semester, the participating teachers and the teaching fellows are asked to complete questionnaires. The purpose of this questionnaire is to triangulate the information provided by the teaching fellows during their focus group sessions and look for additional data with regard to the degree to which the project goals were being met. The questions which are open-ended with the purpose of eliciting a variety of responses, follow.

1. What is your role in the GK-12 grant?
2. To what extent do you feel like you contributed to the team effort in the implementation of problem centered, interdisciplinary learning environments that focus on the application of mathematics to earth science and engineering for middle school students?
3. To what extent do you feel like the others you worked with contributed to the team effort in the implementation of problem centered, interdisciplinary learning environments that focus on the application of mathematics to earth science and engineering for middle school students? (If you have a different answer for different people you worked with, feel free to copy these choices and answer them for each person or role.)
4. To what extent do you feel the activities you implemented were problem centered?
5. To what extent do you feel the activities you implemented were interdisciplinary?
6. What recommendations do you have that would improve the project activities?
7. How would you rate the overall effectiveness of the workshops?
8. How would you rate the overall effectiveness of the classroom experiences?
9. How would you rate the overall effectiveness of the team interactions?
10. What else should we know about your experiences this year or semester?

In a separate section, for teachers only, the following closed response questions appeared, "To what extent has your participation increased your knowledge and understanding of mathematics?" and "To what extent has your participation increased your knowledge and understanding of science?" Both questions were followed by the response categories: greatly increased, increased, neither increased or decreased, decreased, and greatly decreased. Both the teacher and fellow survey concluded with an invitation for respondents to share any additional comments or recommendations.

Teacher Evaluation of Fellows

At the end of the academic year, each participating teacher was asked to respond to a survey concerning the performance of their graduate teaching fellow. Undergraduate teaching fellows were not evaluated since they had only been in the classroom for three months. The questions that comprised this survey were as follows.

1. How would you rate your graduate teaching fellow's performance in your classroom?

   Weak **Adequate** **Strong** **Excellent**

   Please explain your rating.
2. Given the opportunity, would you select to have this fellow work with you in the classroom for another year? Please explain your answer.
3. If your graduate teaching fellow reapplies to this program for another year, do you feel that he/she should receive a second year of support? Please explain your answer.
4. How has the teaching fellow impacted the learning of students within in your classroom? Please explain your answer.
5. Would you like to continue in this program as a teaching mentor for the academic year 2004-2005?

Colorado Student Assessment Program

The Colorado Student Assessment Program (CSAP) is a State mandated test that is designed to be aligned with the Colorado State Content Standards. The purpose of this test is to provide an indicator of students' achievement in reading, writing, mathematics and science in grades 3-10. In the middle grades (6^{th}, 7^{th} and 8^{th}), student performances in mathematics is assessed at the end of all three grade levels and in science is assessed at the end of the eighth grade only.

As part of the assessment efforts of this program, CSAP scores for mathematics and science at the participating schools in grades 6th, 7th and 8th grades were examined immediately prior to the start of the project (academic year 2002-2003) and immediately following the first year of the project (academic year 2003-2004). Currently, the participating teachers' student scores are not available for project analysis. The investigators are working with the State of Colorado to make this type of analysis a possibility in the future.

ASSESSMENT RESULTS

Through assessment, a great deal of information has been acquired that may be used to evaluate the success of the GK-12 Learning Partnership program. This section describes what has been learned through the analysis of assesment data with respect to each of the project goals within the first year.

Goal 1: Cooperation of Practicing Teacher, University Faculty, Graduate Student, and Undergraduate Student

Cooperation between the teachers and the graduate teaching fellows began at the 2003 summer workshop. Evidence to support this claim was provided through the observations completed at the summer workshop and the comments made by fellows and teachers on the workshop comment cards. Both teachers and fellows repeatedly indicated that they enjoyed and wanted more collaborative activities and they were anxious to begin planning collaborative instructional activities. The faculty workshop instructor was also available to assist these teams during collaboration periods.

During the focus groups that were held at the end of the fall semester, the graduate teaching fellows reported that they were respected members of the teaching team. The participating teachers trusted them to plan and implement instruction. Also, the fellows felt that the teachers had a great deal of confidence in the fellows' content knowledge. One fellow even reported that the teacher had used the fellow's lesson plan as an example when requesting classroom funding. The collaboration between the graduate fellows and the teachers, based on the fellows' responses to the spring focus groups, continued to increase throughout the academic year. The bonds between the fellow and the faculty summer workshop instructors were reinforced throughout the year through the on-going fellowship workshops.

The undergraduate teaching fellows began participating in the classroom for five hours each week in January, 2004. By the end of the spring semester, the three undergraduate teaching fellows still expressed uncertainty with regard to their role in the classroom. This was probably attributable to their delayed start, which meant they did not participate in the first summer workshop.

Goal 2: Preparation for Pursuing Pre-college or College Education as a Potential Career

By the end of the first semester, the graduate teaching fellows indicated that they were beginning to understand the nature of the middle school classroom and were beginning to make decisions about their own potential as instructors. For example, one fellow stated that as a result of this project, "[I] Definitely know more about the teaching profession." Another fellow explained that the project is, "Affirming for some – [who] want to be teachers. Others have decided not to teach at this point in their life." One of the graduate fellows is currently considering teaching at a pre-college level and four are considering teaching at the college level. All of the graduate fellows agreed that, as a result of this project, public speaking was no longer a challenge to them.

Given that the undergraduate fellows spent far less time in the classroom, their answers were less definite. They expressed uncertainty as to their future as pre-college or college teachers. The following comment was taken from the spring undergraduate fellows' focus group, "Too early to say if we want to teach. Very good preparation to start answering this question."

Goal 3: Enrich Content, Application and Interdisciplinary Knowledge

On the first day of the summer workshop, the seven teachers took a multiple choice pretest that consisted of twenty items related to (a) applying mathematical and scientific principles to engineering and earth science problems, and (b) understanding educational assessment. On the last day of the workshop, the same test was given to the teachers as a posttest. These data were analyzed using a two-tailed, paired t-test. The standard deviations and ranges were similar on both tests

(SD_{pre} = 2.8, SD_{post} = 2.6; $Range_{pre}$ and $Range_{post}$ = 8). From pre to posttest there was a significant increase in the mean scores ($p = .004$). A disappointing result was that the mean pretest score was eleven and the mean posttest score was fourteen points out of a total of twenty possible points. Although this indicates that by the end of the workshop the teachers had not yet mastered the material, the reader is reminded that the workshop was only eight days long. The investigators had the returning teachers complete this test again during the second summer workshop, after working with the graduate teaching fellows for a full year. The results of this analysis are not yet available.

Goal 4: Implementation of Problem Centered, Interdisciplinary Learning Environments in the Classroom

During the fall and spring focus groups, the undergraduate and graduate teaching fellows described a number of activities that were problem centered and interdisciplinary in nature. Examples include (a) using X-Men to determine which of their characteristics are possible, based on principles of science, (b) learning about area and perimeter through an activity where the students determine how much wallpaper they will need to decorate their house, (c) using an Incredible Machine activity to teach the students about density and geology, and (d) learning about fractions by creating recipes for fruit smoothies.

When the graduate fellows were asked during the fall focus group to describe the impact they have had on the middle school students, they indicated that they were amazed how quickly the students had become attached to them. They were also surprised by many of the students' limited basic skills, which included a lack of proficiency with the addition and subtraction of whole numbers. Three of the fellows wanted to further help these students and volunteered to oversee after school activities that addressed problem solving and technology.

The participating teachers also recognized the strong impact the graduate fellows had on their students. When the teachers were asked at the end of the spring semester, "How has the teaching fellow impacted the learning of students within in your classroom?," the following are examples of their responses:

- Infected a number of them with a love of learning. A great role model for my students, in particular. Developed presentations which simplify and make knowledge easy to learn.
- The students really enjoy her and miss her and ask about her when she is not there. She has developed rapport with some of those at-risk students that have the potential to last a lifetime. She also gives up her afternoon to work with some of those at-risks students and their missing work.
- She has impacted the learning of my students because she is able to connect with the students that I haven't been able to connect with and create a charge in them that makes them want to succeed. One student that flunked first semester is passing currently because of [graduate fellow].
- Additionally, he is an excellent role model that likes the students. He expects the students to be able to do the work. He has helped the students to mature the student thinking to mature. He has an ability to get the kids excited.
- Having someone else in the classroom that could also help guide the students has helped build the confidence of the students as well as improved the math that is taught. An example of this is when we studied acceleration and speed and the students were having a difficult time in completing the math. [Graduate fellow] sat down with a group of kids and worked with them improving their math knowledge and skills.

The teachers also indicated that the fellows where successfully implementing problem centered, interdisciplinary learning environments. The following are examples of their comments:

- We have had a lot of fun creating new activities for the students – activities that increase both student curiosity and learning.
- Her Incredible Machine Activity (during our energy unit) was incredible; she is currently working on a density activity that will allow students to get on a density website while they learn more about density; and she is constantly coming up with interesting websites for the students to work on for both energy and geology.
- He has raised the bar of expectations on the students. He has changed the class by expecting the students to think and utilize mathematics skills. He forces the students to think—he does not just lecture or tell the students what they need to know. He forces the student to re-examine hypotheses and make appropriate conclusions.
- He has an ability to get the kids excited. He wrote a unit on electromagnetism—he brings in stories and videos and examples.
- Having [graduate fellow] in the classroom has been a wonderful addition. I have been able to apply more real world information and bring in engineering examples, which incorporates math and science. The students responded very well to this. [Graduate fellow] helped my students understand how to problem solve by working through with them how an engineer would solve. He has brought new ideas to my students and has more students interested in science.

In order to better understand the impact that the teaching fellows were having on the classroom instruction, the percentage of students that performed at or above proficiency on the CSAP scores in mathematics and science at each participating school were examined for the academic year 2002-2003, immediately prior to the start of this project, and 2003-2004, immediately following the first year of the project. These are displayed in Table 1. Examination of these values suggests that there has been very little change in students' overall CSAP performance in mathematics and science at the participating schools. The reader is reminded that the displayed values include entire grade levels within a school and are not restricted to the students whose teachers participated in this project. The investigators are currently working with the State of Colorado on the possibility of examining CSAP scores of students whose teachers are directly involved in this project.

TABLE 1
PARTICIPATING SCHOOLS CSAP SCORES IN SCIENCE AND MATHEMATICS

	Mathematics						**Science**	
	6th grade		**7th grade**		**8th grade**		**8th grade**	
	2002-2003	**2003-2004**	**2002-2003**	**2003-2004**	**2002-2003**	**2003-2004**	**2002-2003**	**2003-2004**
School 1, Proficient or Above	28%	25%	32%	21%	13%	24%	20%	28%
School 2, Proficient or Above	26%	25%	15%	18%	25%	20%	30%	30%
School 3, Proficient or Above	31%	46%	29%	26%	31%	28%	27%	40%

CONCLUSIONS

As the above discussion suggests, progress is being made toward the achievement of all four project goals. The teaching fellows are developing a clear understanding of what it means to be a middle school teacher and the challenges that middle school teachers face on a daily basis. They are also learning, as they become professionals within their own field, that they have a great deal that they can contribute to the K-12 educational system. Many of the fellows have verbalized a commitment to making pre-college or college teaching a career. Both the graduate and undergraduate fellows have become attached to the students and have developed a better understanding of their skills and interests. The middle school teachers have learned about the fellows' respective area of study and have made the fellows respected colleagues in their school.

Qualitative evidence further suggests that the middle school students are benefiting from having the fellows in their classrooms, both in the cognitive and affective domains. The quantitative evidence concerning students' performances, however, is not as compelling. Based on the CSAP scores in science and mathematics at the school level, there appears to be little change in student performances from the start of the project to the end of the first year. There are several manners in which to interpret this information. First, the presence of the teaching fellows may have little benefit on student learning outcomes. This conclusion, however, is contradicted by the qualitative evidence. Another interpretation of this result is that a year of intervention is too short of a period for the presence of teaching fellows to have a school wide impact on students' learning outcomes. The fellows may have only had an impact on the students that directly participated in their classrooms. Since the investigators do not currently have access to individual teachers' CSAP data, this could not be examined. The feasibility of this type of analysis in the future is being investigated.

ACKNOWLEDGEMENT

The authors would like to recognize the contributions of the participating teachers, Louise Belnay, Denver Fox, Trey Griffin, Chriss Kilburn, Erin O'brien, Anna Reishus, and Sara Spreckelmeier, and the participating teaching fellows, Michael Ewing, Matthew Krugman, Leanne Miller, Agata Miodonski, Que Nguyen, Sarah Shearer, Marc Wennogle, and Tina Ziemek, in the success of this project. The authors would also like to thank Tina Falconer who is the project liaison with the participating district and a Co-PI on this project.

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