Using the Discipline of Agricultural Engineering to Integrate Math and Science

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Abstract

An outcome of a 1998 forum sponsored by the National Research Council was a recognition that topics related to food production and agriculture are excellent mechanisms for integrating science topics taught in the K-12 education system and for providing many avenues for inquiry-based and project-based learning. The engineering design process is also an excellent mechanism that can engage and integrate both math and science topics. From this perspective, faculty from the University of Georgia in collaboration with Jackson County School District in the State of Georgia developed a teacher workshop where the goals were to use a problem-based learning theme that is often engaged by agricultural engineers and to use this theme to integrate math and science horizontally and vertically throughout the middle school and high school curricula. Overall, the entire collaborative project has helped to improve significantly middle school CRCT scores and high school End-of-Course grades in math and physical science.

Introduction

The structure of the curriculum in many schools and universities separate courses such that each course is independent and is focused on one discipline (e.g., mathematics, biology, physics, chemistry) and on one theme or topic within a discipline (e.g., within mathematics, algebra, pre-calculus, calculus, geometry, math for modeling). From an administrative perspective, offering mathematics and science courses in this manner may seem logical, particularly in the middle school and high school settings where standardized testing is used to evaluate teaching quality and thus designed to measure student knowledge acquisition within distinct courses, curricula, or disciplines [4]. In the post-secondary environment, offering autonomous courses reflects an academic structure that delineates faculty by disciplines, a recognition that the principles and methods of teaching differ for different disciplines [3], an organization scheme for instructional support such as books and database retrieval systems [7], and, indirectly, the idea of academic freedom and faculty autonomy. It should be noted that discipline-specific courses are necessary to develop the student's deep understanding but should be one of many components of a broad based education [21].

Many studies from the 1980s and 1990s *(for examples, see [6] and [20]),* indicate most students have difficulties connecting topics that are taught via the autonomous course approach and do not understand the practical use of the topics. Results from a 2000 survey examining the background and experiences of teachers found that 89% of high school science teachers believed that they were qualified to make connections between science and other disciplines and therefore could help students connect theory with practical application, but only 19% of these teachers reported that they took the time to help students make this connection [24]. These numbers were 68% and 12%, respectively, for high school math teachers. Morrison and McDuffie (2009) report that undergraduates who enrolled in math education and science education programs knew how to describe data via graphs and statistics, but they did not demonstrate a deep understanding of how to apply the knowledge gained from the data [15]. In general, high school students are not gaining a full understanding of the basic principles of science and math [8], [18], with nearly 30% of U.S. students entering college in the fall of 2000 having to enroll in remedial science and math courses [19]. The implications of such findings have lead to the restructuring of science and math educational programs.

The National Science Education Standards [16] and the National Council of Teachers of Mathematics [5] provide overarching standards for science and math content that all students should know and indicate that schools should implement strategies of inquiry-based and/or project-based learning. In 1998, the National Research Council's Board on Agriculture organized a forum to investigate ways that agriculture, food, and environmental systems could be used to enhance science education [17]. One outcome of this forum was acknowledgement that agriculture is an excellent mechanism for integrating science topics taught in the K-12 education system and for providing many avenues for inquiry-based and project-based activities. Gorham (2002) and Haury (2002) outline how the engineering design process is an excellent mechanism that can engage and integrate both math and science topics [10], [11]. From this perspective, activities related to agricultural engineering should provide excellent avenues for integrating math and science topics and for inquiry-based and problem-based learning.

Jackson County School District in the State of Georgia, in conjunction with the University of Georgia, has an ambitious plan, which was initiated in 2004, to reform the district's math and science education by creating an environment where teachers are supported and are encouraged to integrate math and science content taught in grades 6 through 12 and to develop strategies for project-based learning. *The primary objective is to improve the quality of edu-*

cation for students in the district by strengthening the math and science educational program at the middle and high school levels. The district's science and math teachers at each school meet on a regular basis and review the content taught in each of their courses. Once a month, the science leader and math leader of each school meet with the district's science and math coordinators and the University of Georgia faculty collaborators for the purpose of reviewing successes and problems associated with the plan. Each June, the university collaborators (two faculty members of the Department of Biological and Agricultural Engineering and one faculty member from the Department of Workforce Education, Leadership, and Social Foundations) teach a 5-day workshop where the objective is to help the teachers develop strategies that can do the following:

- Help bridge the gap between the student's classroom experience and real-life experiences using problem-based learning,
- Allow for content area instruction to be integrated throughout the middle school and high school math and science curricula, and
- Help science teachers understand how math affects their courses and vice versa.

Here, integration of the math and science curricula is defined as creating a continuum of knowledge by building course content horizontally across classrooms within a grade and vertically between grades.

Purpose

The purpose of this manuscript is to do the following:

- Outline a strategy which uses the discipline of agricultural engineering to integrate science and math both vertically and horizontally across the curriculum,
- Describe, using qualitative information, teacher reactions to this strategy, and
- Provide data which reflect the overall success of the Jackson County School District program.

It must be acknowledged here that this manuscript describes only one aspect of the District's overall plan and is not intended to imply that this sole program was entirely responsible for the improvement of student performance.

Methods

Identification of Science and Math Topics

The Georgia Department of Education outlines the basic design of each school district's K-12 curricula, thereby specifying what students are expected to know in each subject and grade; similar curricula specification can be found throughout the U.S.A. The general topics taught in middle school science courses are Earth Science (6th grade), Life Science (7th grade) and Physical Science (8th grade). In high school, students must complete 4 units in natural science--at least one unit of biology, one unit of physical science or physics, and one unit of chemistry, earth science, or environmental science. The fourth science unit requirement can be selected from academic science courses or from approved Career Technical and Agricultural Education (CTAE) courses that meet science standards.

The framework of the Georgia math curriculum engages in a multi-year approach where number and operations, algebra, geometry, data analysis and probability and measurements are taught in each grade with each year introducing more complex concepts and principles.

Integrating the curriculum horizontally within a grade could be accomplished using project-based learning and identifying one or two math and science themes. In the project described in this paper, the aim was to integrate both horizontally within a grade and vertically across grades, which meant that the selected project had to address multiple math science themes (not just one or two). Also, it was desirable to demonstrate how each of the science topics was interconnected.

Workshop Activities

Annual workshops have been used to illustrate the connection between Science, Technology, Engineering and Mathematics (STEM) to allow teachers to explore interdisciplinary approaches for understanding STEM concepts and to develop strategies to help students understand how these concepts are used to solve real-world problems. Teachers in the school district provide input concerning topics that they believe should be the focus of a particular workshop. Since the beginning of the collaboration between the Jackson County School District and the University of Georgia, multiple workshops have been held in order to address the needs of the teachers and cover the vast range of topics listed in the state's science and math framework. The following paragraphs explain activities specific to the 2008 workshop.

Requirements of this workshop were to focus all activities toward the math and science topics listed in Table 1 and to achieve the following:

- Demonstrate connections between multiple

science principles and multiple math principles,
- Provide academic rigor which meets District and State guidelines,
- Require students to explore math and science principles via experiments, interviews, etc.
- Introduce a problem with meaning to the students in the District,
- Provide learning opportunities where students realize how their gained knowledge could be applied in other authentic situations, and
- Offer situations where the students could work alongside professionals.

There are a number of projects that can be used to demonstrate each of the first three requirements, but the last three meant that the demographics of The Jackson County School District had to be considered. This district is located approximately 60 miles northeast of Atlanta, Georgia, and while the eastern part of the county is mostly rural, the western part of the county has become a suburban area of metro-Atlanta. Urban sprawl is a concern of the county's population as elaborated by numerous editorials in the local newspapers. Of the area's 48% increase in population between 2000 and 2008, 42% come from the Atlanta-metro area. In 2002, agricultural census data indicated that the county had approximately 42,000 acres in field crops dropping to just over 24,000 acres in 2007, with the bulk of the change occurring in the western portion of the county nearest Atlanta [22], [23].

Based on the above requirements and the demographics of the county, the workshop activities were developed around the concept of operating a subdivision that has integrated farming activities that supports both the life style (recreation, food, etc.) of the subdivision residents, and the local agricultural economy; in other words, the workshop project was to investigate issues related to a farm subdivision. Conveniently, a newly established subdivision adjacent to a former dairy farm provided the backdrop for the farm subdivision setting and a schematic of this backdrop is shown in Figure 1. This particular location parallels a major highway running through the county and is within 2 miles of one of the district's middle schools, which allows teachers to visit the site if deemed necessary. The participants considered several questions, including the following:

- How to maintain and utilize the natural resources in order to have an economically viable working farm,
- How to assess the effects that the subdivision and farm would have on these natural resources,
- How to maximize the positive impacts that the farm would have on the subdivision and vice versa, and
- How to minimize the negative impacts that the farm would have on the subdivision and vice versa.

The participants in the workshop investigated the fundamental principles of mathematics and science needed to develop models that could be used to answer these types of questions.

Figure 2 illustrates how issues and activities associated with agricultural engineering practices can be used to align math and science topics horizontally and vertically. These types of questions allow the students to investigate many issues separately. For example, the 6th grade can investigate Earth Science principles using soil erosion experiments and use the Uni-

Figure 1. A schematic of the layout of the farm subdivision used by the workshop participants in order to investigate issues typically faced by an agricultural engineer.

versal Soil Loss Equation to demonstrate the math principle of scaling while the 7th grade can investigate runoff and the loss of yard fertilizer nutrients meeting the education performance standards of human impact on the environment and the use of math models to understand relationships between variables. The flexibility that the farm subdivision provides allows the teacher to formulate questions that match specific areas of focus, correspond to student interest, and/or meet the needs of enrollment where students can transfer in or out of the curriculum at any given grade level. It is important, however, that teachers allow students to reflect back to the previous grade level activities, keeping a general focus on a theme-based project. This reflection back on previous work is needed in order to align topics not only horizontally within the grade but also vertically across grade levels [13].

Data Analysis

This overall project has been on-going for only 5 years; therefore, there is not enough collected data at this time for a complete statistical analysis. Only positive or negative trends are reported herein. Information has been collected from three sources in order to gauge the effectiveness of each workshop and on the overall project.

The first set of data was gathered through daily informal discussions with the workshop participants and through discussions with the science and math leaders of each participating school. Qualitative data were collected for determining the effectiveness of the workshop to encourage teachers to integrate math and science topics.

The second set of data was collected through the use of criterion-reference tests with one test given just prior to (pre-test) and one given just after (post-test) the workshop. All participants, regardless if they were science or math teachers and regardless of grade levels that they taught, were assessed for their understanding of both the science and math concepts taught at a specific workshop. A total of five workshops have been held. These data are used to determine any positive or negative trends that the workshop had on teacher knowledge of material content.

The third set of data was the results from middle school math and science CRCT exams and the results of high school End-of-Course (EOC) exams. This set could only be used to assess improvement within the high school population and within the middle school population as related to the entire project and not just the workshop.

Results

Strategy used to integrate math and science topics

During the workshop, participants provided daily feedback primarily focused on the effectiveness of lectures, materials and activities. Comments regarding *what was best about the farm subdivision theme* included the real-world nature of the problem and the use of a single theme to integrate math and science principles at multiple grade levels. During the fall term of school, some of the participants reported specific examples of incorporating the theme into lesson plans, such as using mathematics/function families to interpret real data collected during erosion experiments and using a quadratic

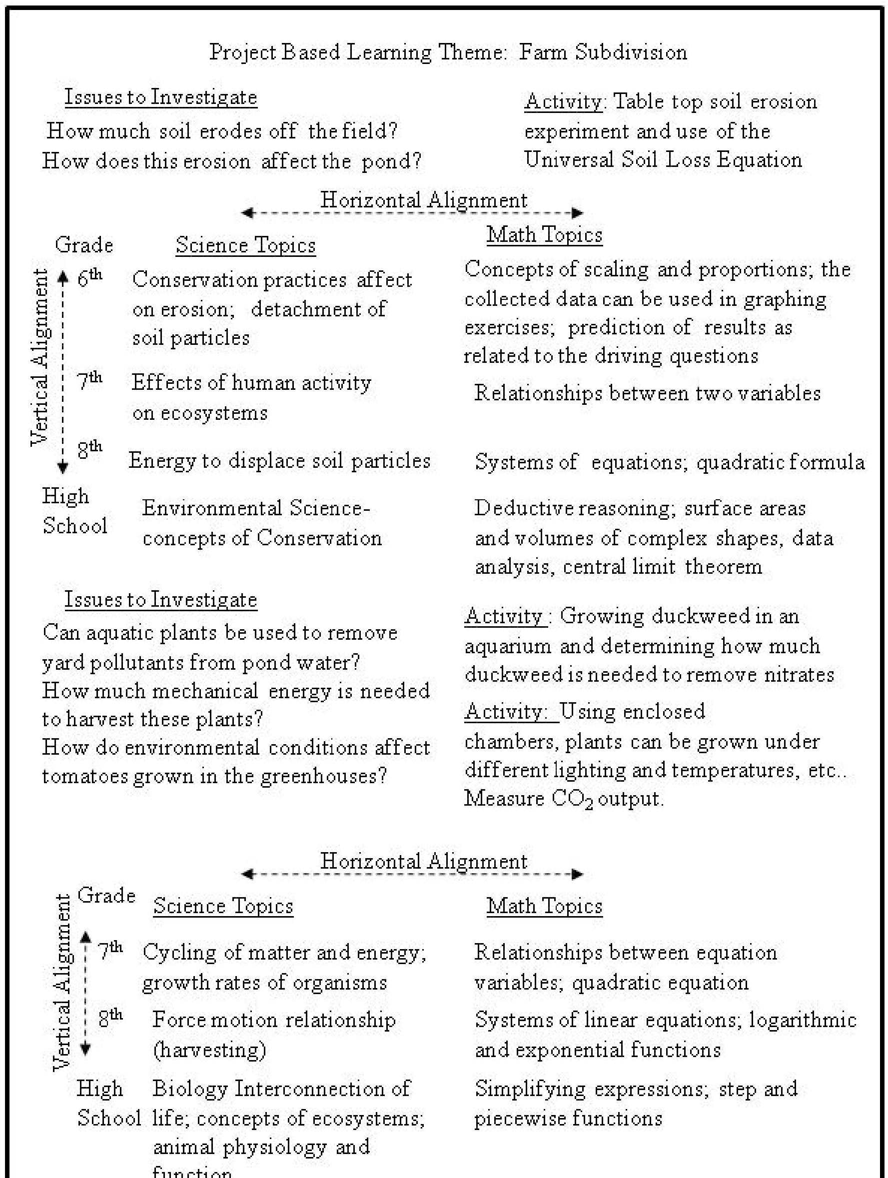

Figure 2. The farm subdivision theme provides several opportunities to align both vertically and horizontally middle and high school curricula.

regression model to predict the effects of nitrogen on plant growth. Common criticisms were related to the assumption that participants had the background to handle the various topics surrounding the farm subdivision theme and the fast pace of the workshop. A few participants indicated that the math and science concepts presented in the farm subdivision theme were too difficult for their grade level. Most participants requested more time to investigate different approaches to incorporate the concepts of the farm subdivision into their individual classroom activities and to develop strategies for vertical and horizontal integration of the material into the 6-12 curricula.

Recommendations for workshop improvement included the following:

- Continued use of interdisciplinary real-world themes to demonstrate math-science integration,
- Focusing instruction more toward hands-on activities and experiments associated with the specific theme, and
- Separating workshop lectures and activities by grade level and by the discipline background of teachers.

Effects on Teacher Content Knowledge

Pre- and post-tests were used to assess the math and science content knowledge of all of the participants. In other words, math teachers were assessed for their knowledge of scientific principles as well as mathematical principles and vice versa for science teachers. The tests were not grade specific, although the participants represented grades 6 through 12. Table 1 provides a summary of the test results from the 2008 summer workshop. Overall, the 33 participants answered correctly an average of 37% more questions on the post-test than on the pre-test; the standard deviation was 14% with a range of 15% to 65%. Table 1 also provides a summary of the test results from the 2007 workshop where the focus was on physical science and its associated mathematical principles. For that workshop, the scores improved by an average of 30% with a standard deviation of 11% and a range of 12% to 52%.

Effects on Standardized Test Results and on End-of-Course Exams

Georgia law, similar to most states, requires that school districts assess students in grades 3 through 8 in the academic areas of reading, language arts, mathematics and science and that these assessments be made using the Criterion-Referenced Competency Tests (CRCT). At the high school level, students are required to take a standardized End-of-Course (EOC) Test for mathematics (specifically algebra and geometry) and science (specifically biology and physical science). The middle school CRCT scores for science (Figure 3) indicate that 8th grade student performance improved from being significantly below the state average (2002) to being significantly above the state average (2008). Similar results were found for student performance in the 6th and 7th grade CRCT science scores. The middle school CRCT scores for math (Figure 4) indicate that 8th grade student performance increased from below the state average to above state average with a rate of increase close to 3% per year. During the same period, the state average CRCT math scores for 8th grade increased at a rate close to 1.9% per year. Jackson County 7th grade CRCT math scores have increased approximately 1.4% per year, while the state 7th grade CRCT math scores increased approximately 0.8% per year. Overall, there appears to be a trend that middle school student performance in math and science has increased compared to the state

		Average Percentage of Questions Correctly Answered		
	Topic	Pre-test	Post-test	Change
Summer 2008	Earth Science	22%	76%	54%
	Life Science	72%	98%	26%
	Photosynthesis	39%	68%	29%
	Mathematics	23%	76%	54%
	Chemistry	38%	75%	37%
Summer 2007	Force and Motion	53%	96%	43%
	Heat Energy	45%	86%	41%
	Electricity and Magnetism	73%	90%	17%

Table 1. The effect of the workshops on the content knowledge of both math and science teachers in grades 6 through 12.

average.

High school student performance on the EOC Test improved for both algebra and geometry (Figure 5). In 2007, the state made changes to the math curriculum; thus, a dip in the EOC scores occurred, but a rebound is seen in the 2008 scores. No significant changes were seen in biology and physical science. However, it should be noted that the 2008 workshop was the first time biology and life sciences were of a major focus and the scores of the End-of-Course Test have not been reported by the State at the time of this manuscript.

Discussion

Project-based learning is an approach where the central focus is to engage students in a project that investigates the concepts of a given discipline or disciplines. For decades, this approach has been used in engineering, medical, and similar professional academic programs. In the early 1990's, primary and secondary school systems began to embrace the concepts of project-based learning and today, K-12 students are commonly engaged in projects that enhance their learning experience. Blumenfeld et al. (1991) indicate that this enhancement is due to increased student motivation and cognitive engagement and that project-based learning increases student comprehension of math and science concepts [1]. A project based learning activity can be designed to help students connect course material to issues affecting their lives [9] and to engage in cross-disciplinary study [14]. A major objective of the summer workshop described herein was to provide strategies that increased students' comprehension of math and science by engaging the students in projects that were authentic and which required cross-disciplinary study. From this perspective, the farm subdivision theme appeared to hold great potential for meeting this objective, and based on comments from the participants of the workshop, this potential was met.

Several publications provide guidelines for developing project-based learning activities, and the study by Hung (2009) will be the focus of this discussion [12]. Guidelines indicate that:

- The chosen theme should focus on a limited amount of content so that the student can develop a deeper understanding and not be distracted by other information that is not part of the intended content,
- The teacher must be able to provide orchestrated and flexible activities in order to avoid

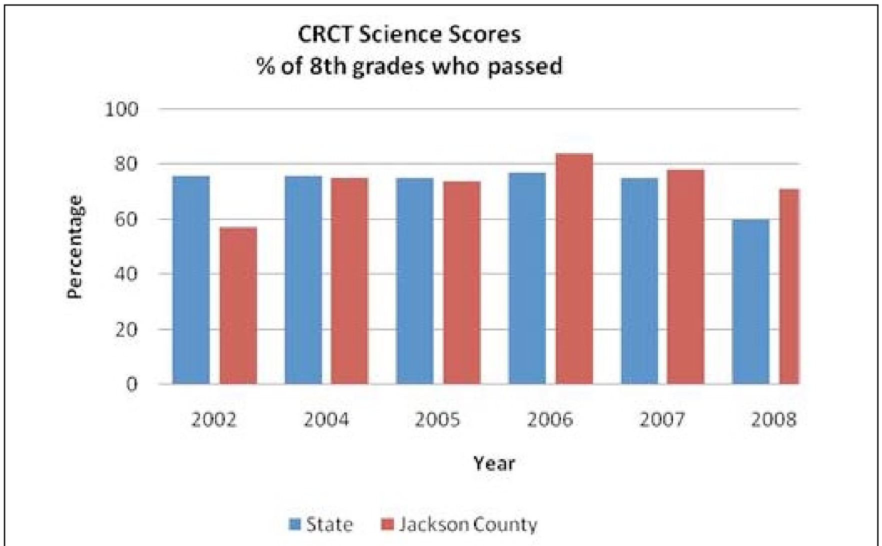

Figure 3. CRCT science scores indicate that the overall project has improved Jackson County School District's student performance in middle school.

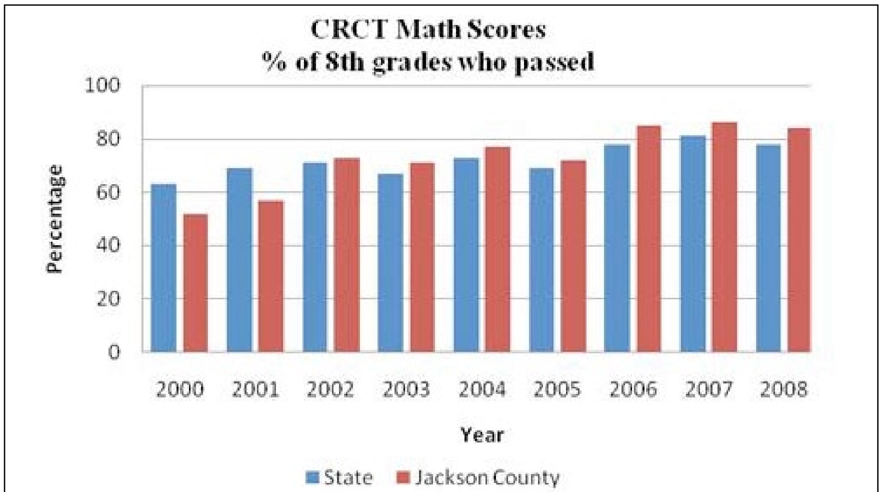

Figure 4. CRCT math scores indicate that the overall project has improved Jackson County School District's student performance in middle school.

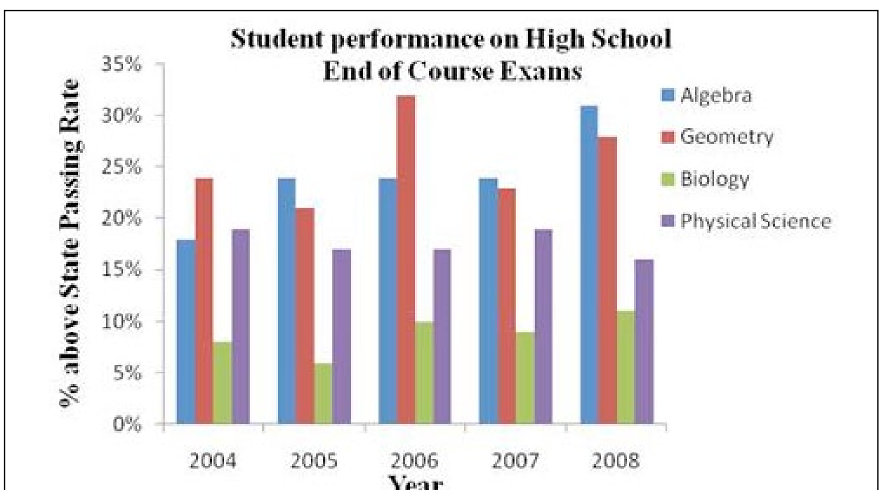

Figure 5. End-of-Course exam scores indicate a potential positive trend for studentperformance in math but science scores are inconclusive.

students "free-forming" their efforts to learn whatever they want, and

- The project should offer alternative paths that can be followed while remaining in the knowledge domain in which the instructor intended the student to engage.

The farm subdivision themed project fits these three guidelines very well. First, teachers can tailor a portion of the project to a specific grade level thereby limiting the amount of science and math content that the students need to understand. For example, 6th grade teachers would be able to investigate soil conservation topics without engaging in topics found in biology or physics. Second, there are specific topics that need to be considered for the proper operation of the farm subdivision; therefore, the teacher is able to guide students without having to provide directed answers. For example, the teacher can focus on plant growth models but the student can choose what plants to grow and the environmental conditions that would affect plant growth, such as plants grown in the farm pond to remove pollutants or grown in the fields (or greenhouse) for the produce market. Third, each problem can be solved via many different approaches and thus students may develop answers based on individual interest, background or available resources. For example, one student may wish to grow algae in the farm pond in order to generate an alternative fuel while another student may wish to grow algae as a food stock supplement. Figure 3 illustrates how a single problem can be used at different grade levels to investigate different science and math concepts and to demonstrate how the development of an answer involves multiple science and math disciplines.

Cohen (1987) demonstrates that in order to align curriculum material both vertically within a grade and horizontally across grades, it is critical that each teacher know the value of each discipline and how each discipline is interconnected [2]. From this perspective, the use of a farm subdivision themed workshop (and other themed workshops) appears to have helped increase the math and science content knowledge of all participants. However, long term effects cannot be assessed at this time due to the current timeline of the project, and further investigations are needed to determine long term effects of this work.

The overarching goal of this project is to improve the quality of education of the students in Jackson County School System by strengthening the math and science educational program at the middle and high school levels. Since the beginning of this project, science and math CRCT scores of the school district have steadily increased, indicating that for the middle school curriculum, this goal is being met. The End-of-Course exam results for high school math indicates a trend of increased student performance. However, due to the shifting of the State's high school math curriculum, it is difficult to determine if the overarching goal is, in fact, being met. The 2008 workshop was the only workshop held to date where biology and life science were the major focus of problem-based learning, and implementation in the classroom has just begun. Therefore, it is too early to detect any positive or negative trends related to student performance in these subject areas.

Conclusion

Science and math teachers have expressed satisfaction with the use of a farm subdivision theme to engage students in interdisciplinary activities and to help demonstrate the practical use of course material. The use of a 5-day workshop to help teachers develop lesson plans focused on this theme appears to have also helped increase the teachers' content knowledge of both math and science. Overall, the strategy of engaging agricultural engineering issues into project-based learning for the integration of science and math topics and for vertical alignment and horizontal alignment of the science and math curricula appears to be successful.

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