Implementing a Whole-School STEM Program: Successes, Surprises, and Lessons Learned

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Abstract - This paper describes results from a two-year-old Whole-School STEM Initiative at Laing Middle School of Science and Technology in Mount Pleasant, SC. This Initiative uses engineering design and technological tools to address mandated curriculum standards in all subjects, including Fine Arts. The program’s goal is to teach students to solve a wide variety of problems using appropriate tools from science, technology, engineering, and mathematics. Over a three-year period, the program expects to add several new facilities to be completed in 2015. Approximately 30% of students presently enrolled qualify for the Charleston County School District’s free and reduced lunch program, which means that it accepts all students who live in a specified geographic area, as well as approximately 100 additional students from outside this area who apply for admission. The school’s current enrollment is about 700 students, but is expected to increase to around 1,200 whennew facilities are completed in 2015. Approximately 30% of students presently enrolled qualify for the Charleston County School District’s free and reduced lunch program.

The objectives of Laing’s Whole-School STEM Initiative are to:

- Provide all students with skills needed for success in 21st century careers;
- Foster potential interest in STEM professions;
- Improve academic performance; and
- Narrow achievement gaps.

Most current STEM programs focus on grades 9-12; of 315 public “STEM schools” identified during the 2007-2008 academic year, 86% were high schools, 10-11% were middle schools, and 3-4% were elementary schools [1]. Yet, the K-8 grades are critical to efforts that hope to increase the number of STEM professionals since many students, particularly girls, lose interest in science and mathematics somewhere between ages 9 and 12 [11].

Index Terms - STEM, Middle school, cross-curricular

Introduction

During the past decade, there has been growing interest in “STEM education.” As of the 2007-2008 academic year, there were at least 315 public “STEM schools” in the United States [1]. Reasons for this interest include:

- Concerns about the shortage of scientists and engineers in the U.S. workforce [2, 3];
- Perceived need for a “technologically literate” society [4]; and
- Improved academic performance associated with activities that enhance student interest and motivation [5, 6].

The acronym “STEM” literally stands for science, technology, engineering, and mathematics; but interpretations of its exact meaning vary widely. These range from very specific (e.g., mathematics, chemistry, physics, computer / information sciences, and engineering [7]) to very broad (e.g., “an assemblage of practices and processes that transcend disciplinary lines and from which knowledge and learning of a particular kind emerges”[8]). There is a similar variety of ideas about the scope of “STEM education,” including:

- Individual curriculum subjects titled “science,” “engineering”, “technology,” and “mathematics” that collectively are referred to as “STEM,” but which may be taught separately with little or no integration between them;
- A career cluster (analogous to “Health Care” or “Hospitality”) that includes professions in science, technology, engineering, and mathematics; or
- Projects or activities that involve various aspects of science, technology, engineering, and/or mathematics, and that may or may not link to specific standards [9].

These diverse interpretations often contribute to confusion among educators [10] and others who have critical roles in effective STEM education.

In this paper, we describe our experience with a “Whole-School STEM Initiative” that integrates STEM content into all subjects in a middle school curriculum.

Overview of the Whole-School STEM Program

I. Design

The Whole-School STEM Initiative described here is being developed at Laing Middle School of Science and Technology in Mount Pleasant, SC. Laing is a partial magnet school, which means that it accepts all students who live in a specified geographic area, as well as approximately 100 additional students from outside this area who apply for admission. The school’s current enrollment is about 700 students, but is expected to increase to around 1,200 when new facilities are completed in 2015. Approximately 30% of students presently enrolled qualify for the Charleston County School District’s free and reduced lunch program.

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The importance of including all students in Laing’s STEM initiative derives from our understanding that every student will live and work in a world that is highly influenced by science, engineering, and technology. To function effectively in 21st century workplaces and societies, students need the ability to understand and evaluate technology in its many forms [4]. Moreover, we believe that many students may have a latent but unrecognized interest in STEM professions that can be revealed and developed through personal involvement with applications of these disciplines.

The central strategy of Laing’s Whole-School STEM Initiative is to use engineering design and technological tools to address mandated curriculum standards in all subjects; ideally in a cross-curricular format. In addition to mandated standards, the foundation for this strategy includes Standards for Technological Literacy [STL; 12], and Core Technologies adapted from those developed by the Maryland State Department of Education [13]. This strategy embodies defined best practices for STEM schools [14, 15], and includes many attributes of Project-Based Learning [16].

II. Implementation

Initial steps in the development of Laing’s Whole-School STEM Initiative have been previously described [9], and included four months of planning with educators and administrators in the spring of 2012, identification of program activities for sixth grade classes to be undertaken during the 2012-13 academic year, and professional development during the summer of 2012. Planning, training, and implementation activities for the Initiative have been facilitated by a full-time STEM coach.

A major obstacle encountered by many K-12 STEM education programs is a shortage of educators equipped to undertake classroom activities envisioned by the programs [15]. At the outset of Laing’s Whole-School STEM Initiative, no educators considered themselves adequately trained for such a program, and most voiced some degree of apprehension about the perceived need to master unfamiliar and intimidating disciplines; particularly engineering.

The key to addressing these issues has been to emphasize problem-solving using tools of the STEM disciplines, as opposed to education about the content of these disciplines. In the words of one educator, “We aren’t trying to create classrooms full of little mini-engineers. Our goal is to help our students become STEM Thinkers, who know how to solve a wide variety of problems using appropriate tools from science, technology, engineering, and mathematics.”

Central to this emphasis on problem-solving is the engineering design process (EDP), some version of which is included in most STEM curricula. Laing educators quickly realized that this process can be applied to many problems beyond the purview of engineering and design. English language arts (ELA) and social studies instructors were able to find particularly robust connections to their subject standards, which prompted one educator to propose that the instructional goal should be, “Every child, every class, every day: Engineering, some way.”

Educators’ comfort level with the idea of applying the EDP on a daily basis also has been enhanced by identifying the close correspondence of EDP steps with those of the Mastery Teaching Model, which was previously established as part of instructional best practices at Laing Middle School. The first step of both processes is particularly important: Understand the problem and/or desired outcomes. Beginning a class with this step identifies what is expected from the day’s activities, and provides the opportunity to identify the purpose of the activities, and to link them to a real world context.

In addition to developing students’ abilities to apply the EDP to diverse problems, a primary objective of the Whole-School STEM Initiative is to expose students and educators to a variety of technological tools that they may apply in various problem-solving scenarios. The scope of this objective is defined by the STL and Core Technologies: During their three-year tenure at Laing, the program aims to address all of the STL benchmarks, as well as provide hands-on experience with all Core Technologies. Examples of activities that have been developed to meet this objective include:

- Greenhouse Design/Build (6th grade; ELA, Social Studies, Science, Math)
- Earthquake Hazard Mitigation (8th grade; ELA, Social Studies, Science, Math)
- Salt Marsh Restoration (7th grade; ELA, Social Studies, Science, Math)
- LED Pop-up Books (6th grade; ELA, Marine Science, Art)
- Kinetic Art Sculptures (8th grade, Advanced Art)
- Alternative Energy Research (6th grade, ELA, Science)
- Materials Research (6th grade Social Studies, 8th grade Science)
- Ocean Exploration (all grades, ELA, Social Studies, Science, Math, Marine Science, Art)

Extra-curricular clubs and competitions offer important opportunities to encourage students’ interest in STEM professions, and Laing’s program includes a FIRST Lego robotics team, SeaPerch underwater remotely operated vehicle team, and a trebuchet team that competes in a local Storm the Citadel competition. An unfortunate shortcoming of these activities is that they include only a small fraction of the school’s students, either because of conflicts with students’ other activities or due to constraints imposed by the competitions’ rules. This limitation underscores the importance of including diverse hands-on activities as part of the regular school day to provide experiences that may ignite and encourage student interest in STEM professions.
RESULTS

I. Formal Assessment

Most of the results discussed in this paper are primarily anecdotal and subjective due to the evolving nature of the program, as well as the short timeframe during which it has been active. We are presently working with faculty at the College of Charleston to develop more rigorous assessment tools focused on the specific objectives of the Whole-School STEM Initiative.

Despite these constraints, the limited formal assessment data presently available are noteworthy. In 2012, Laing Middle School’s Index Score under the federal Elementary and Secondary Education Act (ESEA) Accountability System was 81.5 (of a possible score of 100). In 2013, Laing’s ESEA Index Score had increased to 98.5 [17, 18].

Additional data are provided by the South Carolina Palmetto Assessment of State Standards (PASS) tests, which are administered to South Carolina public school students in grades three through eight to measure student performance on the South Carolina Academic Standards in five subject areas: writing, English language arts (reading and research), mathematics, science, and social studies. Results of PASS tests provide a measure of achievement gaps, which are reflected in the percentage of students who do not meet grade level standards in these subjects. Table I compares the percentages of Laing students who did not meet grade level standards in 2012 and 2013 [19]. In all five subject areas, the percentage of students not meeting standards declined by an average of 23%. At present, the influence of the Whole-School STEM Initiative on these results cannot be determined, but such results are nevertheless encouraging.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Percent Not Met 2012</th>
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<th>Percent Change</th>
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<tr>
<td>Writing</td>
<td>17.5</td>
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II. Student and Parent Perspectives

In addition to formal assessments, subjective understanding and perspectives of students, parents, and educators are highly important to successful STEM programs [15]. Educator perspectives are treated in the following section. Examples of student and parent perspectives are provided in Tables II and III, respectively.

III. Educator Perspectives

When STEM was introduced at Laing, our first responses were:

“not another initiative”;

“what is this STEM and how will it affect us?”; and

“how much more are we going to have to do?”

As educators saturated with new initiatives and “the next big thing,” it would be an understatement to say we were hesitant to start this process.

Reflecting on our initial response almost two years later, it is clear that we were asking the wrong questions. We

TABLE II

TABLE III

TABLE I

COMPARISON OF 2012 AND 2013 PASS DATA FOR STUDENTS NOT MEETING GRADE LEVEL STANDARDS AT LAING MIDDLE SCHOOL

“the thing that I like about STEM the most is the building and problem solving. I think other schools should start doing it. Some things that I have learned from STEM is teamwork, how to build a greenhouse, and to problem solve.”

“STEM is very fun. We get to learn new things and have fun while doing it. It makes me excited to come to school everyday!”

“I like STEM because it will help prepare us for working hard on our own with a couple of other members. We will learn to think outside the box too. I feel that STEM will enhance our understanding of what we will be dealing with in the world.”

“What I think about STEM is that it’s a way for kids to learn amazing things that we can do in the world that we’ve never heard of. STEM is something we all should value.”

“STEM is great. I think it is educational yet fun at the same time. It’s hard to find things like that especially at school. It is fun because it has hands on projects in class, and at the same time it also teaches teamwork.”

“It gives us time to solve real problems without being robots.”

“She looks at problems in a more organized way. She also sees the connections between classes when they are working on similar projects.”

“He is happy to work on the projects and is excited to do the research.”

“He seems to grasp the concepts more easily and is excited about the projects that he works on. I have also noticed many ‘real world’ applications that he is connecting to what he is learning.”

“It is so much more important that our kids learn how to solve problems and understand how things work than simply to get them to remember facts. I believe the STEM curriculum instills this type of learning that they will continue to build on and will better prepare them for the world they live in.”

“I’ve seen my child take more pride this year than in years past. He shares stories of learning and his grades mirror his enthusiasm.”

“He now looks forward to school.”

“He comes home excited about the choices of figuring out which option will work better in the projects and he talks about all the choices and outcomes.”

“She is excited about the topics studied and actively participates.”

“He loves going to school. I see a huge improvement in his math and science work.”

“He stays much more focused with STEM.”

“She is much more excited about learning.”

“My daughter loves the opportunity to do hands-on learning.”
should have been thinking about how STEM would affect our students’ learning, curriculum and instruction, and collaboration with our colleagues across disciplines. These are the areas in which we have seen the most dramatic changes since we implemented a Whole-School STEM program.

Faculty collaboration at our school looks a lot different than it did two years ago. For this approach to be successful, educators must work together and understand each other’s curricula. This not only helps enrich our lesson plans, but also creates unity among our teachers. Students are able to see that their classes are connected. If the ELA teacher is building on a science, social studies, or math lesson it becomes obvious that these are not separate subjects. In fact, they are complementary. Students stop questioning, “Why are we working on this in an ELA class?” as they understand that we do not work in isolation. Building these connections for the students is the backbone of a successful STEM program.

A STEM focus enhances our instruction and curriculum by providing real-world connections and hands on opportunities in every subject area. Through real-world problem solving, students are invested and engaged because they are not just “playing school”. In our ELA classes, presentations that had previously been the typical end of unit assignment have turned into lively debates about “what is the energy of the future.” Instead of writing narratives for the teacher’s eyes only, they create picture books with pop-up illustrations and light emitting diodes. This goes beyond a fancy STEM activity, and leads to important curriculum-related conversations. Students have in-depth discussions about characters and climax as they select which pages to light and pop up.

We regularly use the EDP to facilitate learning in each content area, teaching students to become problem solvers, and broaden their perspective. Having students look at their school subjects through the lens of the EDP changes the way they approach the content. For example, our students in social studies class are able to use the EDP to examine the progression of technology from the ancient world to modern times. Instead of the teacher giving notes on the needs and challenges of the ancient cultures, they are able to determine these needs based on what the ancient cultures created. They understand that people in the ancient world encountered problems, came up with solutions, but were always trying to improve. This is the process that we encourage all students to take when solving problems presented to them in school, as well as in the real world.

Once we overcame our initial concerns about STEM and began to learn what it was all about, it became clear that it was not “one more thing”. In fact, it makes education more interesting and engaging for teachers and students alike.

IV. Surprises

Our greatest surprise to date has been that the effect of Whole-School STEM on our students’ learning has been much more profound than we initially expected. Students who have not been previously successful or interested in school have shown new capabilities as STEM begins to drive our instruction. Some of these students have become leaders in the classroom; transformed from the reluctant, bored individuals we were used to seeing.

Honors students have been affected as well, but in different ways. Most of our chronically successful students have become skilled at identifying “the right answer” and understanding what is needed to satisfy the educators’ expectations. Solving open-ended problems challenges these students in new ways, because the “right” answer is usually unknown to the educator, and there may be multiple solutions that are equally acceptable. Students who are accustomed to success are highly averse to what they perceive as failure, and want to avoid situations in which their initial response may not be acceptable. At first, this created frustration, but as the year continued students became independent problem solvers who understand that being wrong is okay and is often an important part of finding a solution. The cyclic nature of the EDP reinforces this understanding, and helps create the expectation that revision and repeated attempts are the norm rather than the exception.

LESSONS LEARNED AND NEXT STEPS

1. Lessons Learned

Results described above, while still preliminary, are sufficiently positive to have attracted attention from other schools that are considering similar initiatives. Our general advice includes:

A. Develop a comprehensive vision that establishes the overall scope of the initiative, desired outcomes, and an implementation process that can proceed in small steps. Educator buy-in is essential, and adequate time must be allowed for a pre-implementation planning process that identifies and responds to individual interests, abilities, and concerns. Initial activities should link familiar practices and content with essential STEM concepts, such as the EDP.

B. Projects can be intimidating, particularly if they are cross-curricular and involve unfamiliar technologies. On the other hand, projects that are overly simple, trivial, or sporadic may not engage students’ interests, nor contribute much to their technological abilities and understanding. It is important for educators to understand that they do not need to have answers for all possible questions, nor do they need to have projects fully designed before students become involved. The type of program described here depends upon educators who can facilitate student learning, rather than engage in a large amount of direct instruction.

C. Communicate regularly and substantively with parents to build their understanding of how a STEM focus helps academic performance as well as builds 21st century workplace skills. Many parents have skills that can complement a STEM initiative, and can provide technical support to supplement educators’ skills.

D. Expect, watch for, and discuss surprises, particularly input from students and parents, which can reveal important though unexpected opportunities.
E. Be skeptical of turnkey solutions. There are numerous commercial STEM-related products that can be very useful if they are matched to the particular needs and skills of a specific initiative; but none can substitute dedicated educators who understand their program and are invested in its implementation.

F. A positive attitude is a major asset. A group that approaches a problem believing, “We can solve this” is often correct.

II. Next Steps

A major priority for Laing’s Whole-School STEM Initiative is to build robust partnerships with businesses and community organizations. Such relationships are an obvious potential source of financial support, but we envision additional roles that include:

- Participating in developing curriculum content that accurately portrays 21st century industry;
- Providing authentic workplace experiences;
- Providing venues for teacher professional development;
- Providing mentors for student projects and activities; and
- Assisting with outreach efforts to other schools and community organizations.

An important step in building these relationships is to ensure that prospective partners understand the objectives and approach of our initiative, as well as the realities of middle school education. To foster this understanding, we encourage visitors to experience our programs first-hand, observe classrooms, see some of our products, and talk with students and educators.

CONCLUSION

Our experience with the Whole-School STEM Initiative at Laing Middle School has underscored an important 21st century reality — More than ever before, learning is an ongoing necessity. About 640 years ago, Geoffrey Chaucer described a mindset that might be a model for today’s STEM educators: “And gladly wolde he lerne, and gladly teche;” or, as we say about students and educators at Laing, “We are all learners; we are all teachers.”

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REFERENCES


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