AC 2007-1857: SUPPORTING MATH AND SCIENCE THROUGH ELEMENTARY ENGINEERING IN ELEMENTARY EDUCATION

Charles Parsons, Douglas L. Jamerson, Jr. Elementary School

CHARLES PARSONS is the Science Coach at Douglas L. Jamerson, Jr. Elementary School Center for Mathematics and Engineering. He earned a B.A. in Elementary Education from the University of South Florida. His experiences include over 30 years teaching in Kindergarten through fifth grade classrooms and 1 ½ years as a resource teacher. Chuck has curriculum writing experience and has presented at various state and national venues.

Debbie O'Hare, Douglas L. Jamerson Jr. Elementary School

DEBORAH O'HARE is a 4th and 5th grade teacher at Douglas L. Jamerson, Jr. Elementary School Center for Mathematics and Engineering. She earned a B.A. in Elementary Education from Florida State University and has National Board Certification. In 2006, she was one of the finalists for teacher of the year for her district. Her experiences include over 21 years as a classroom teacher in all grades. Her main focus has been in the intermediate grades. Presently, she “loops” with her class from 4th to 5th grade, thus keeping them for two years. Deborah has experience writing curriculum using the Backwards Design Process and has worked with the state to create, revise and edit the math questions used on the statewide test for fifth grade.

Robin Little, Douglas L. Jamerson Jr. Elementary School

ROBIN LITTLE is the Engineering Coach at Douglas L. Jamerson, Jr. Elementary School Center for Mathematics and Engineering. She earned a B.A. in Elementary Education and a M.Ed. in Educational Leadership from the University of South Florida. Her experiences include over 23 years in early childhood classrooms and seven years as a teacher resource and trainer. Robin has curriculum writing experience, including a nationally published teacher resource book integrating science and literature with other areas of the curriculum.

Pat Van Driessche, Douglas L. Jamerson, Jr. Elementary School

PAT VAN DRIESSCHE is a fourth grade teacher at Douglas L. Jamerson, Jr. Elementary School Center for Mathematics and Engineering. She earned a B.S. in Elementary Education from the University of Wisconsin-Superior and her M.S. in Specific Learning and Behavior Problems from the College of St. Thomas, St. Paul, MN. Her teaching experiences include over 30 years teaching first through sixth grade and seven years in exceptional student education. Pat has presented various district trainings and is currently involved in the development of the integrated curriculum at Jamerson.

Kim Parsons, Douglas L. Jamerson, Jr. Elementary School

KIM PARSONS is the Reading Coach for Kindergarten through Third grade at Douglas L. Jamerson, Jr. Elementary School Center for Mathematics and Engineering. She earned a B.A. in Elementary Education from Florida Atlantic University and a Master of Arts in Education from the University of South Florida. Prior to her position as Reading Coach, Kim’s experience included fifteen years as a classroom teacher in grades one through five. Kim has presented at various county and state venues.

Marilyn Barger, University of South Florida

MARILYN BARGER is the Executive Director of FL-ATE, the Florida Regional Center for Manufacturing Education housed at Hillsborough Community College. She earned a B.A. in Chemistry at Agnes Scott College, and both a B.S. in Engineering Science and a Ph.D. in Civil Engineering from the University of South Florida. She has over 16 years of experience in developing curriculum in engineering and engineering technology and is a registered professional engineer in the State of Florida. She is currently working with Douglas L. Jamerson, Jr.

Elementary School to develop curriculum content for its Center for Mathmatics and Engineering.

Richard Gilbert, University of South Florida

RICHARD GILBERT is a professor of Chemical Engineering in the College of Engineering at the University of South Florida. He has developed educational materials for ISA (Instrument Society of America), AVS (American Vacuum Society) Science Educator's Workshop, and the National Science Foundation through a grant to develop high school science and math curriculum content. He is currently working with Douglas L. Jamerson, Jr. Elementary School to develop curriculum content for its Center for Math and Engineering.

Supporting Math and Science through Elementary Engineering in Elementary Education

An engineering curriculum in an elementary school environment is possible but by the nature of the student body very different from all other school levels. Many children come to school with a rich background due to being provided many opportunities outside of school. However, a large part of our population has minimal background knowledge when entering school. In a kindergarten through fifth grade program the elementary teacher deals with illiterate to middle grades or better readers and children with no number sense to children who are ready for algebra. In science, the child may be scientifically illiterate and filled with misconceptions to scientifically literate and ready to explore concepts at a higher level. This paper outlines how our school has developed a model that supports children in both mathematics and science development using engineering concepts as the guiding tool.

Who are We?

Douglas L. Jamerson Elementary School was built in 2003 in a predominantly ethnically isolated inner city neighborhood. Its location facilitated ethnicity integration without the aid of a district assigned plan. During its first year of operation, the school applied for and received a grant from the Magnet Schools Assistance Program (MSAP) that provided additional resources to support its curriculum and faculty development. The school has a K-5 student population with no special enrolment criteria and definitely functions as a typical full service neighborhood school. It has more than 600 students and at least 3 classrooms at each grade level. Student talents and abilities are normally distributed and there is no grouping of mainstream students by sections, test scores, and/or perceived ability. Every teacher at each grade level is expected to present the same curriculum and the topics and the order of these presentations is driven by lesson plans that are horizontally and vertically integrated. Since engineering naturally integrates, and therefore emphasizes three of the four national priorities under the American Competitive Initiative[1], we believe that our integrated mathematics and science engineering approach is a productive and effective way to reach students from various ability and economic levels. This approach forces each teacher to find ways to use these subjects to strengthen the understanding of the engineering topics being taught which then, in turn enrich the student's core science and mathematics learning experiences.

Engineering Models in an Elementary School

Currently there are at least three models of engineering curriculum development for K -12 students. Each is useful within the constraints of its proper application. In the "Drive by Engineering 1" model, a graduate student, practicing engineer, or museum personal, develops one or more lessons on a given topic and delivers them to a class over a given time period. The classroom teacher and students are observers and/or participants in the lessons. Then the presenter leaves and "engineering" is finished because the teacher has no background knowledge with which to continue. Within this model, it would be hard to prove any lasting science or mathematics knowledge base impact on the students or the teachers. However, the approach does increased general connections that exist among science, mathematics and engineering.

The second method, "Drive by Engineering 2", is also developed outside of the school by graduate students, engineers, or museum personal; the lessons are written by others for teachers to deliver and may have cross grade correlations. There might not be training for the teachers on how to implement the engineering lesson, so the teacher delivers the lessons and hopes for the best because he/she has no background knowledge to fall back on when confronted with a problem, unexpected question or outcome. Also, since the teachers were not part of the writing process, they may have misconceptions that never were corrected or are missing important elements that were understood by the writer. Most of these lessons are delivered during the science block of time and have no integration with other subjects. Therefore, critical connections are lost and no real application occurs.

Both of these methods represent "shotgun" approaches that may introduce activity-based discovery learning on a particular science topic. They also may focus on a problem solving process, or even design process, which can help enhance the students' interest in the topic as well as the puzzle of how to "approach" solving everyday problems in a systematic method. Certainly these can be valuable experiences for children. However, they don't allow the child to explore in depth or make connections between math and science concepts which are an integral part of an engineer's view of the world.

A third approach, the "Drive into Engineering" model, puts the teachers and the students in the middle of the engineering activity. The teachers have created the moment and then both groups are immersed in it. For Douglas L. Jamerson Elementary School this represents a "hands-on, minds-on" approach that fosters the development of methods and activities aimed at the integration of mathematics and science concepts we are expected to teach imbedded in engineering concepts and principals that provide meaning and reinforcement to the lessons being taught. It is the model that lets us personify our motto, "The Force that Accelerates Learning".

Integrated Units of Study

The curriculum at Jamerson is structured as seven integrated units of study that are based on the Sunshine State Standards and incorporate engineering principals to magnify the learning effect. While some schools have chosen to adopt the Standards for Technology Literacy as their sole vehicle for promoting engineering ideas, we have chosen to use our state standards for math and science to drive our building of engineering concepts. Since engineering is the application of math and science this seemed to be a logical choice. Technology is prominent throughout our curriculum units but is not the main focus. Our curriculum is being constructed using the backwards design model developed by Wiggins and McTighe[2], the teachers are writing the integrated curriculum with the support of an engineering coach, science coach and university engineering professors. The curriculum meshes science principles and engineering design practices, spiraling upward through all grade levels. As it is written the engineering professors meet with grade level teams to review completed work and guide the next steps. It is checked for alignment with the standards and clarity of purpose related to engineering concepts.

One of the main instructional strategies used throughout the units is the implementation of the Jamerson Engineering Design Process modeled after the Informed Design Process[3]. Our design process is used throughout the day in all subjects to provide a framework for students to solve problems and adapt their thinking based on experiences, models, etc. at an early age. Our end results is a curriculum that represents a tangibly reinforcement of Petroski's views about early education[4] and Miaoulis' opinion that "Engineering in these (early) grades offers a wonderful range of problems and projects" that can encourage a child to "pull together a range of disciplines and see a project through from start to finish". [5]

As suggested above, our curriculum units are vertically and horizontally aligned in order to ensure mastery of concepts by the end of the fifth grade. The units are being continually redesigned to strengthen the math and science skills taught in an effort to develop the engineering concepts. This redesign is driven by the increase in base skills that our students have as they move through the grades. For example, our current fourth graders have a baseline math and science experience base that is noticeably above previous fourth graders which, happily means we can increase our expectations of this class. Below is a table that details the vertical alignment of the Electromagnetism strand.

Electromagnetic Force and Resultant Motion Strand		
Grade Level	**Science and Engineering Concepts**	**Examples**
Kdgn.	Introduces **sources of energy** (fire, electricity, and battery) through nursery rhymes such as *Jack Be Nimble.*	• Candle to electric light • Making a model candle then changing it to an electric candle showing power from electric cord and/or battery
1st	Introduces **waves** and their characteristics in different mediums.	• Building a box instrument • Make simple circuit with picture from a model
2nd	Introduces **magnetic field, simple circuits,** and **open and closed systems.**	• Building a maglev vehicle that performs to set criteria
3rd	Introduces **conservation of energy** Introduces **circuit diagrams, series and parallel circuits**. Finds **voltage.**	• Designs and build a thermal insulator • Design and build a series and a parallel circuit
4th	Uses knowledge of transfer of energy and heat. Collects data with temperature probes. Analyzes data Introduces **calculations of work and power**, **diagrams** and **technical drawings.** Determining **gear ratio** for **mechanical advantage.**	• Building solar collector • Building a solar vehicle • Calculating power • Sketching technical drawing of solar car
5th	Uses knowledge of **circuits** to create a telegraph**.** Makes **circuit diagrams.** Calculates **amps, volts** and **resistance**.	• Calculating electromagnetic forces. • Designing and building a telegraph that will meet specific design criteria. • Completing a cost analysis of the

		telegraph design.

Elementary Mathematics and Science within an Engineering Framework

Traditional elementary science lessons are very qualitative, not quantitative. Primary students develop some observational skills that may include some data collection. Intermediate students will do some data analysis that includes median recognition and mean calculation to help support a hypothesis about a general observation such as plants in sun light grow taller than plants in the dark. Although arithmetic does play a significant role in some elementary science activities, with the exception of scalars such as temperature, there are few elementary school science experiences that require the manipulation of a measurable scalar to determine a parameter that reflects any intrinsic characteristic of the material or system under investigation.

Elementary science classes traditionally use a textbook as the driver of the curriculum. In a typical science class, students spend time receiving core knowledge via teacher lectures and/or demonstrations. Elementary teachers often fall back to what they are comfortable with when teaching science. Thus, many elementary science lessons are designed around animal habitats, plants, and the study of space. These are often stand alone learning experiences that allow for some hands-on activities, such as drawing a habitat, measuring plant growth, and making Paper Mache planets but have limited merit as integration tools. The experiments the children are engaged in are demonstration or visual in nature with no real world application. These activities might minimally develop fundamental science concepts but are certainly not tied to any focused math lesson, except in the casual way a graph or plot summarizes a science fair project results. Such lessons do address a science standard but do not expand on any opportunity to bring depth to the student's understanding of the standard addressed. For example, there are many science lessons in which students might built a circuit to see if they could make the light bulb light, but they never would have used tools to measure circuit parameters so that resistance and/or power can be calculated. Nor do any of the lessons that involve magnet movements also require students to quantitatively investigate field strength and directions.

The curriculum at Douglas L. Jamerson elementary School is structured so that science lessons are predominately quantitative and usually lead to an engineering design challenge that requires science knowledge and supporting mathematical manipulations to support the student's design effort. A fourth grade design challenge provides an example. In one car design scenario, the best rubber band car design results in a car that can travel a specific distance but no further. This challenge is counter culture to the typical race car challenge because the principle design criterion is energy optimization not power consumption. Pre-design science lessons focus on the gravity concept with respect to mass, force (weight), and rolling friction. Pre-design mathematics lessons deal with the scalar multiplications that deal with unit conversions and energy calculations. Students design a prototype car with hands-on activities that direct their attention to energy calculations for rubber band stored energy based on distance test runs.

Although the inclusion of engineering into science and math lessons does expand the depth and breadth of both lesson types, it is not easily accomplished within an isolated science or math lesson. In addition, the non-negotiable expectation that instruction in both mathematics and science meet state standards, require that teachers have lessons that demonstrate this expectation as an assessable deliverable. All of this effort to tie the math and science concepts and state standards together ultimately allows the student to make predictions, draw conclusions, and make sense of outcomes based on the collected data. In the car example just presented, this leads to the student making final design choices and developing an operational protocol that will result in a car that optimally crosses the course finish line with no energy reserve and minimal excess distance traveled beyond that finish distance.

One way we glean the instructional time to accomplish math/science integration required for our design challenges is to creatively use the traditional instructional time blocks to accomplish the task. Since our classes are "self-contained", one teacher teaching all subjects, the science/engineering block and math block of time can be seamlessly woven in order to maximize time and provide students ample opportunities for discovery, manipulation and data analysis. Another component of the instructional logistics puzzle is to extend the math lesson structure to strengthen the concepts of number sense, scalars, and vectors manipulations so they can be taught as early as possible. Whether it is the vocabulary that teachers use or the problem solving that students do, students are introduced to numbers and scalars through activities developed for their abilities at an early age. By fourth and fifth grade, students are manipulating vectors computationally in applied physical environments.

For elementary students this is not a trivial endeavor so most vector calculations they deal with should describe situations that have parallel or orthogonal vector configurations. However, fourth and fifth graders do comprehend and can perform graphic vector arithmetic on two vectors at any angle. For elementary teachers it represents a change from the abstract to real world. Elementary teachers seldom develop a sense of scalars with students and usually only associate units with numbers as required when delivering lessons on time and money. Using engineering as a learning framework allows students to be introduced to situations that require the calculation of force, work, power, speed, etc. as parameters that connect the engineering science of a situation to a design parameter. This focus also leads to early association of the scalar manipulations to pre-algebraic manipulations of icons (variables) associated with these scalars.

Results

To promote the possibility of Douglas L. Jamerson, Jr. Elementary School students having an authentic engineering experience, our curriculum is closely linked to the science and mathematics instruction given to every student. For this to happen, the science curriculum has been vertically and horizontally aligned from kindergarten to fifth grade. Units and lessons address Florida Sunshine standards and are guided by national standards of science and grade level expectations. Concepts are introduced in kindergarten and developed in appropriate steps until a fifth grade student demonstrates mastery. At the higher level, the math is integrated naturally and not seen as a stand alone concept. Also throughout the school year concepts are built upon within a grade level so that core concepts may be visited three or more times (see electromagnetism matrix referenced above).

Our students have access to computer based sensors systems. The students use these science tools to facilitate mathematical activities and promote engineering projects. For example, another car design challenge in the 4th grade curriculum does focus on power. For the car test phase of that challenge, students do drag race their cars in a grade level championship event. For this school wide spectator event, a drag strip is laid out in the cafeteria and computer monitored motion detectors are installed on the start and finish lines. In qualifying races for the big event, students determine speed and power parameters from hand acquired weight, time and distance data. Excel calculations are used in fifth grade for various project data analysis and result graphing.

The use of computer based sensors has lead to increased interest of students in how technology can be used for a learning tool. This has carried over into other learning environments such as improving their technology skills (use of search engines, accessing websites…). This improvement has been assessed using a teacher developed rubric. As students use technology as a part of an integrated curriculum they begin to develop the schema of tool not toy.

Finally, even though we have flexibility in our curriculum design, our students are still held accountable by their performance on standardized tests in reading, math, and science. This includes state wide Florida Comprehensive Achievement Tests (FCAT). A result summary for the math and science tests is provided below.

Florida Comprehensive Assessment Test Math Results			
Grade Level	**2004**	**2005**	**2006**
3rd	286	295	311
4th	296	307	303
5th	309	328	317

As evidenced in this table that shows results from the inception of Douglas L. Jamerson, Jr. Elementary, the composite scores in math have risen as you look diagonally, reflecting students who have been in the Math and Engineering program from the beginning. When individual student scores are broken down 59% of our students are high performing, 67% are making gains, and of our lowest 25% of students 61% are also making gains.

Science scores have not been disaggregated by student, as baseline data has just been established. But in the two years that the test has been given to fifth grade students the composite scores also show growth. 2007 will be the first year test scores will be broken down by student and school. We hope to be able to provide those results at the time of our presentation.

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