AC 2005-1404: ADAPTING THE ENGINEERING DESIGN PROCESS FOR ELEMENTARY EDUCATION APPLICATIONS

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Adapting the Engineering Design Process for Elementary Education

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Introduction

Kindergarten through fifth grade students are uniquely challenged each and every day they attend Douglas L. Jamerson, Jr. Center for Mathematics and Engineering (DLJCME). As a new elementary school in the Pinellas County (FL) School District, in 2003-2004, Jamerson's administration and staff have been charged with the task of building an elementary school with a math and engineering focus. After one academic year, Jamerson is well on its way. The school is recognized by the United States Department of Education as a Center for Mathematics and Engineering for Elementary Education. The mission for DLJCME is to promote, facilitate, and improve the use of mathematics and the understanding of science among its students by integrating mathematics, science, and engineering design within every subject and across each grade level at Jamerson Elementary.

D.L. Jamerson's overarching goal is to present required standards-based curriculum as a learning adventure that is enriched by applying engineering skills (integrated knowledge of mathematics, science, language, history, and the arts) for problem solving and higher order thinking at the appropriate level in all classrooms and subjects. The execution of its curriculum is not the production of a collection of miniature things like pyramids or volcanoes. Nor are Jamerson students in the gadget, robot, widget, and/or thing-a-majig creation business. DLJCME uses the engineering design process and its associated engineering projects as the foundation of an instructional strategy to help its students gain important conceptual understandings as well as develop secure problem solving skills. At Jamerson, design activities emphasize design challenges that rely on mathematics and science skills also being taught at each grade level as well as any relevant knowledge and skills developed, learned, and secured in earlier grades. This approach prompts inquiry and analysis as well as discourse among students and teachers. It also leads to project concept closure which is seldom accomplished in many trial and error design efforts. A vision of the schoolwide curriculum is illustrated in Figure 1, which was developed by the Douglas L. Jamerson Core Team during its early goal setting workshops before the school officially opened.

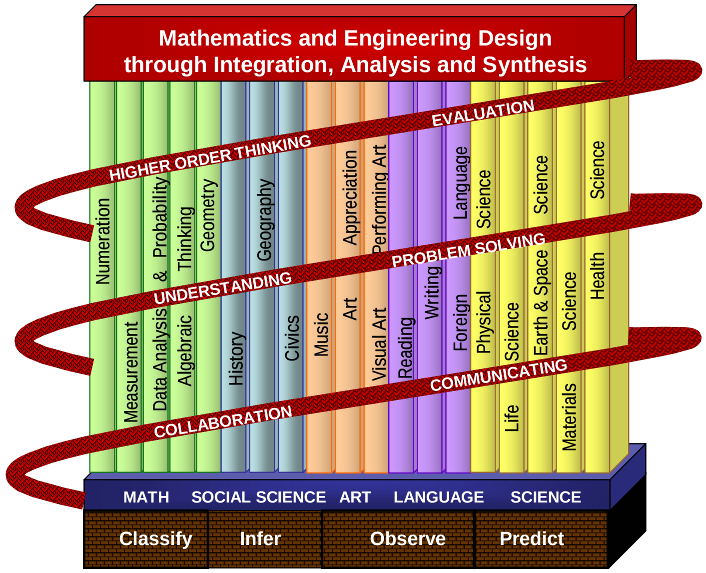

Figure 1. Douglas L. Jamerson Elementary School Integrated Curriculum Diagram

The Engineering Design Process at D.L. Jamerson CME

The design process has always been essential to engineering. The design and then construction of a pyramid, for example, was much more than a series of trial-and-error problem solving situations. The engineering portion was the process of successfully overcoming all of the problems, confirming that the selected problem solution really worked, establishing a uniform way to apply the solution and then transferring the knowledge to other problems still to be solved or tasks to be accomplished. The end of the experience this time was a pharaoh's tomb that was also an impressive structure that would last for all times. The final shape was the results of interactions among the builders, engineers, politicians, religious leaders and, of course, the pharaoh. Thus, the structure's shape, size and interior details, its role in Egyptian society, and its construction plan were known and agreed upon before the first great stone was put in place.

Jamerson Elementary School's use of its own version of the engineering design process has an enormous impact on each child's elementary education. The Jamerson Design Process is arranged into four color-coded groups (stages): **PLAN, DESIGN, CHECK,** and **SHARE.** The detailed steps are outlined as follows:

PLAN (red)

- Identify the design problem
- Investigate (research) the problem
- Clarify design limitations and requirements

DESIGN (blue)

- Generate design alternatives
- Choose the best option and explain why
- Develop a design model or prototype

CHECK (green)
- Test and evaluate the design solution
- Modify the design to meet developing needs

SHARE (purple)
- Communicate achievements

A design process is not a sequence or series of steps. During any engineering design process (i.e., the design of a toothbrush or the creation of a great pyramid) all the activities listed above are included AT LEAST once. It's also important to know that these activities do not have to be done in the order listed. Some of these activities might be repeated many times to get the final design "just right". All that is required is that every design process includes all of the activities at some time or another during the whole design process.

To develop the Jamerson Design Process, teachers, administrators, and engineering professors examined several different examples of other design processes. Then through brainstorming discussions and creative problem solving, the nine steps were decided and wording was created that was suitable to the elementary school audience. In order to allow the younger students to actively engage and remember the design process components, the four broader group headings were developed with a specific color code. For the primary children, although the nine components are referred to and available for their use, the color and simplicity of the **PLAN**, **DESIGN**, **CHECK**, and **SHARE** stages allow even the youngest children in kindergarten to use the vocabulary at a level that is developmentally appropriate. While the intermediate students use all nine components, having them grouped into the four larger stages helps them organize their thoughts and assignments, as well as communicate with the younger students.

Faculty Development for the Jamerson CME Design Process

To be sure that all of the teachers, staff, and administrators took complete ownership of the Jamerson Design Process, they worked through the process with a simple design challenge over two days during their pre-school preparation days. The challenge was to work in groups by grade level to design and build a mobile within the time allotted that was instructional and illustrated their first unit of science and how they would relate it to engineering and the design process. The teams were given some time on both days of the pre-school activities to specifically work on their projects. Each grade-level team was joined by one or more curriculum specialist or administrator. In addition to the design and build, each team would have to present its mobile and demonstrate that it met the design constraints and met the design objectives.

During the **PLAN** stage, the teacher teams asked questions to <u>identify the design problem</u>. They <u>investigated the problems</u> through discussions and some used the Internet for a further clarification of the term "mobile". Then teams <u>clarified design limitations</u> which governed the use of materials and design due to a short production time limitation. Safety is one of the most important design requirements and as such represents the final unalterable limitation on all aspects of the design process. In the **DESIGN** stage, often called the "heart" of an engineering design, some teams brainstormed, sketched, and/or created hands-on trial and error possibilities to <u>generate design alternatives</u>. <u>Choosing the best option</u> for most groups became a simultaneous activity as team members discussed various design alternatives. Other teams <u>developed a design</u>

model or prototype first and then generated alternative designs by exchanging materials during construction or physically moving the different parts around. This was a practical approach since the mobiles were relatively simple to build and the materials were inexpensive. This approach is probably the best way to start for tactile learners as long as the design challenge is not large, expensive, or time-constraining.

In the **CHECK** stage, teachers had to test and evaluate the design solution they chose for their team mobile. Before they could start testing, they checked the plan stage so that all criteria would be tested. Then they had to decide how to evaluate their designs and how to score the test results. Some used the "trial and error" approach and modified the design to meet developing needs. Others used formulas they had learned to try to test and rebuild what didn't match the criteria. Other groups used a combination of the steps by testing different materials first before including them in the design of their mobile. Finally, in the **SHARE** stage, teachers were required to communicate their achievements by reporting the final design to the targeted audience in an effective and appropriate manner. The teams shared informally with their colleagues through oral presentations and demonstrations. They were also asked to document their achievements either through written paperwork, such as well-labeled sketches, or through media options such as digital pictures or video.

The resulting mobiles were proudly hung in each grade level area at the beginning of the school year. Some of the intermediate grade students were even given a similar assignment as family take-home project. The mobiles served several purposes including a visual reminder to the teachers of the Jamerson Design Process in action. The mobiles were also a centerpiece for conversations with classroom visitors and parents illustrating the Jamerson Design process. Finally, the mobiles served as teaching tools for the instructional messages they contained.

Classroom Implementation of the Jamerson CME Design Process

Jamerson's students are now implementing the Jamerson Design Process in their classrooms on a daily basis. This investigative approach requires each child to constantly apply the skills they are acquiring from all of their subjects (reading, mathematics, science, social science, art, and music). For one of the introductory activities in fourth grade, the students were given a design challenge to build an airplane and airport out of polygons. Each of their projects were to include the following design criteria: 1) a square or rectangular shaped cardboard for the ground; 2) a colored runway and ground; 3) two large rectangular towers with square roofs out of construction paper; 4) one long rectangular building for the passenger terminal; 5) a long rectangle, a large isosceles triangle, and a small isosceles triangle which will become the plane's body and wings, and a quadrilateral with their choice of angles for the tail of the plane; and 6) the plane must not be attached to the ground or runway.

For this specific example, fourth grade major curriculum components were addressed. These included geometry standards, oral presentation skills, and social study elements. In general, the projects facilitate the integration of engineering principles across the curriculum.

For the **PLAN** stage, the children were asked to make a plan to meet the design requirements, think about how they would build the buildings and airplane and decide what steps they would use to complete the project. For the **DESIGN** stage, the fourth graders each sketched their airplane and airport and then built their towers, terminal and airplanes. The students were given questions, such as “Did you change your original design?” and “If you changed your design, what problems did you have that made you change your design?” to help them **CHECK** their designs. Then they were directed to list any changes they would like to make if they were to make another similar project. In the **SHARE** stage, the students were asked to prepare a three minute presentation of their design concept and how their final product reflects the design challenge. Although the polygon airports and airplanes looked very different as shown in the photographs below, each followed the Jamerson Design Process.

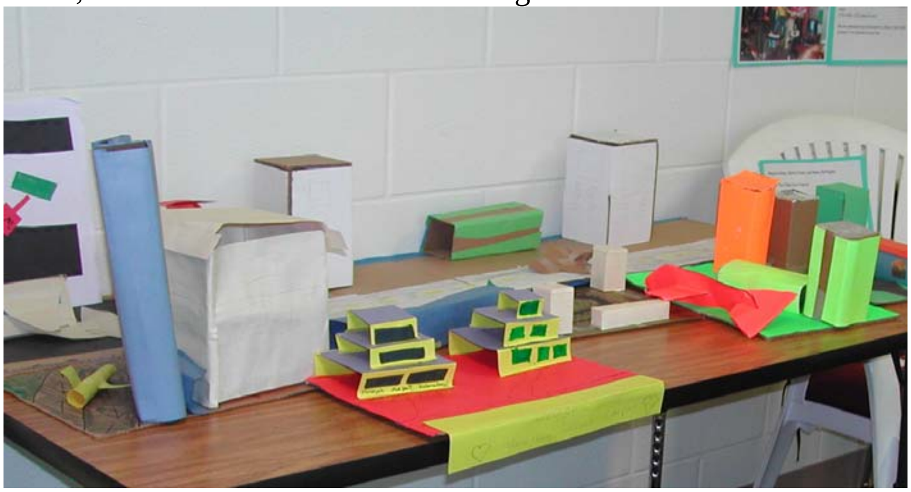

Figure 2. Some examples of fourth grade design challenge for airplanes and airports made with polygons.

Figure 3. Kindergarten students observe the fourth graders’ polygon airports and airplanes during Jamerson Expo.

As they worked through the stages, the fourth graders integrated knowledge from different subject areas including math skills of geometry and measurement; reading, social studies, and technology as some students researched in books and on the Internet about airplane designs as well as what components might be needed to make a successful airport; and science skills needed to make an airplane shape simulating a design that would be able to fly in real life.

In turn, as Jamerson students of all ages work on projects for other interdisciplinary subjects, they are encouraged to use the Jamerson Design Process to help them meet the design criteria for whatever the challenge. For example, when students work during Writer's Workshop time, they first **PLAN** their piece. During this time, they basically "think" about their writing and do some mental planning. In the **DESIGN** stage, the students will create what their piece will be. Older students might use a planning sheet to remind them of necessary elements, but this stage includes the actual writing piece. In the **CHECK** stage, they examine their work to see if it contains criteria that would be expected at their grade level. For the younger students, they might be looking to see if they started sentences with a capital letter and ended them with some form of punctuation. Intermediate students might be looking for the important elements of beginning, middle, end and other criteria like thought, action, or dialogue strategies taught in mini-lessons.

As with the engineering aspects of using the Jamerson Design Process, the **SHARE** stage here is critical as well. Students are required to communicate their work with their peers. They not only read their piece, but share what elements of good writing they included and how they might improve on their writing. In these activities, students become teachers for their classmates as they learn about each other's strengths and weaknesses as well as see how peers use skills learned in class.

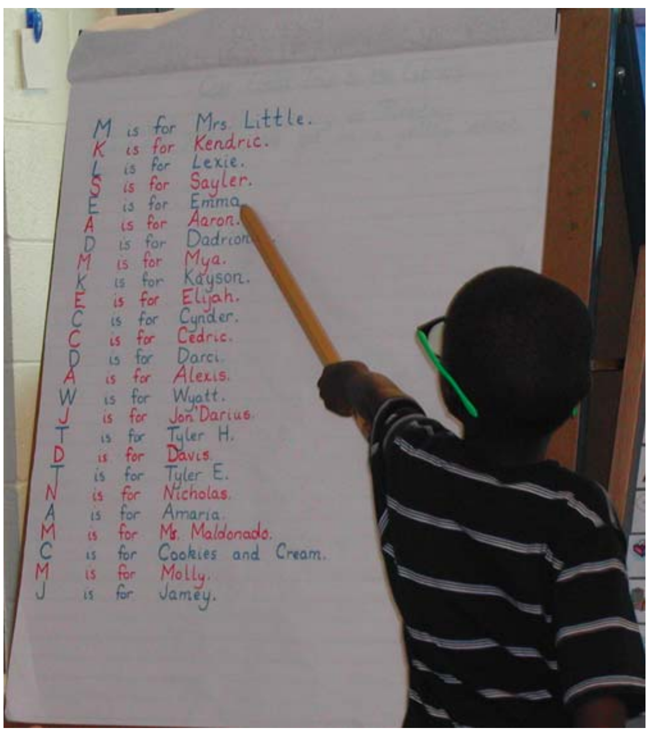

Figure 4. Kindergarten child **CHECKS** class predictable writing for punctuation element.

Conclusion

As Jamerson students proceed through learning challenges, an observer will see the Jamerson Design Process's impact on the way the students think. One can watch how the children attack any problem and then listen to each student's analysis of the situation. Observers will be pleased and perhaps amazed at the orderly and thorough way the task is accomplished. They will certainly enjoy the twinkle in each child's eyes as he or she explains, with some detail, the mathematics and science that work behind the scene of the problem to ensure the success of the project. Jamerson students are helping to shape their own learning paths by becoming problem solvers of and for the future.

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Authors

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