UASPP: Helping Middle School Teachers Devise Their Own Hands-on Engineering and Science Activities

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Abstract

The University of Arkansas Science Partnership Program (UASPP) focuses on the professional growth of 6th, 7th and 8th grade science teachers through summer institutes and follow-up activities. Teachers are teamed with engineering faculty to improve teaching skills and to increase the teachers' use, understanding and application of hands-on exercises. The 27 participants in the Year 2 (2007) Institute developed 18 open-ended design briefs and activities for use in their classrooms during the academic year.

Follow-up visits showed that the participants were very active in using design activities during the 2007-2008 school year. The 21 surveyed teachers used 73 teacher-developed design activities for an average of more than 3 activities per teacher. Best of all, 19 new design activities were developed by the 21 surveyed teachers after the Institute, and one teacher developed six new activities for the classroom.

Following a very successful Year 2 Institute and follow-up activities, sweeping changes in preparing the Year 3 Institute were not warranted. The Year 3 Institute will further teach the participants how to implement the "design loop" in their classrooms as a systematic approach to solving problems, and expand the design briefs to include mathematics. Additional U of A faculty will participate in the Institute and be available for follow-up activities during the academic year. Middle school math teachers will also participate in the Institute and, along with middle school science teachers, will prepare design exercises that integrate material between math and science teachers working at the same school.

Introduction

The National Science Foundation has recognized the need to introduce engineering and science to middle school students, or even earlier, to increase the number of students entering engineering disciplines.[1] Most students in the middle level grades (6th, 7th, and 8th) are unaware of engineering and do not recognize engineering as a rewarding career option. To more effectively prepare students in the pursuit of engineering and science degrees, students should be encouraged to develop the critical thinking skills necessary for solving problems in the real world.

It is universally accepted that all student benefit from hands-on learning activities in the classroom. Studies show that hands-on activities are especially important for English language learners (ELLs), and are therefore an important way to tap this increasingly large and diverse pool of future engineering students. [2, 3, 4]

In 2005, the College of Engineering and the College of Education and Health Professions at the University of Arkansas formed a partnership to assist the Northwest Arkansas Education Renewal Zone (NWA-ERZ) in engaging students in hands-on, standards-based science activities that help to form the base for the engineering discipline. This University of Arkansas Science Partnership Program is a three-year Summer Institute program funded by the Arkansas Department of Higher Education which focuses on the professional growth of 6th, 7th and 8th grade science teachers from 23 schools in the NWA-ERZ. The Program teams teachers with engineering faculty to improve teaching skills and to increase the teachers' use, understanding and application of selected laboratory exercises. It includes classroom/laboratory instruction, follow-up activities at the schools, and evaluation, both during and after the institute.

While the Year 1 (2006) Summer Institute focused on providing engineering hands-on activities that teachers could subsequently use in their classrooms,[5, 6] the Year 2 (2007) Institute taught the participants how to design their own experiments using a reverse design teaching method called the "design loop" method which emphasizes results-driven outcomes.[7] The design loop approach focuses on three components: 1) a clear set of desired results by identifying goals for students, the specific information the students will understand , and what students will achieve as a result of the learning activity; 2) the identification of assessment evidence, allowing teachers to develop performance tasks to evaluate student results; and, 3) the creation of a learning plan that includes activities for students, enabling them to achieve the desired results.[8, 9] The purpose of this paper is to summarize activities from the Year 2 Institute, as well as the follow-up implementation activities that were performed by the teachers during the academic year. The use of this information in planning and development of the Year 3 Institute is also discussed.

The Year 2 Summer Institute

Getting Started

The first step in putting together the Year 2 Institute was to obtain commitments from middle school teachers to attend the Institute. Since this was the second of three planned summer institutes, the 28 teachers from the Year 1 Institute were of course asked to attend the Year 2 Institute. As expected, there was some attrition; four previous attendees had changed teaching assignments and two teachers lacked support from their current school administration. As a result, 22 previous and 5 new attendees representing 12 middle and junior high schools attended the Year 2 Institute.

A consultant with experience in the design loop method was hired to teach the two-week Institute. Mr. Brad Dearing is Head of the Technology Department of Illinois State University High School. Mr. Dearing has B.S. and M.S. degrees in Technology Education from Illinois State University, serves as president of the Technology Education Association of Illinois and serves on the Advisory Board for the Technology Department at Illinois State University.

Engineering faculty from the University of Arkansas assisted Mr. Dearing during the workshop, and also observed and participated in follow-up activities during the academic year.

Institute Activities

An overview of the daily Institute activities is shown in Table 1. The workshop lasted four hours per day for two consecutive weeks. Each participant received the textbook *Understanding by Design*, 2nd edition, by Wiggins and McTighe,[10] and was provided a "toolkit" consisting of a typical worker's toolbox (approximately 1ft x 2ft x 1ft) and a large Rubbermaid® container (approximately 2ft x 3ft x2ft) with tools and miscellaneous supplies inside for use throughout the program.

Table 1. Overview of Year 2 Institute Activities

Day	Activities
1	Introductions; Overview/Agenda; Needs Assessment; What is Engineering Design Problem Solving?; What is a Design Brief?; Work through a Design Problem; Daily Feedback
2	Pre-test; Group/Teamwork Activity—Toxic Popcorn; Creating Design Briefs; Work through a number of Design Examples; Daily Feedback
3	Group/Teamwork Activity—Human Knot; Work through a Design Problem--Buoyancy; Present Design Solutions; Daily Feedback
4	Group/Teamwork Activity—Group Juggle; Analysis of Designs; Work through a Design Problem—Spinning Wheels; Ties to Arkansas Curriculum Frameworks; Daily Feedback
5	Group/Teamwork Activity—Aerospace Design; Construct a Design Brief Activity; Daily Feedback
6	Demonstration of River Bed Simulator; Finish Design Briefs; Gather Materials; Daily Feedback
7	Swap and Perform Someone's Design Briefs; Daily Feedback
8	Finalize and Test Designs; Present Results; Daily Feedback
9	Post-Test; Group/Teamwork Activity—Traffic Jam; Finish presenting results; Daily Feedback
10	How will you use Design Problem Solving in your classroom?; Resource Exchange; Overall Feedback Survey

As is noted in Table 1, the daily schedule included a teambuilding activity at the beginning of each session. For example, the teachers especially enjoyed the day two "Toxic Popcorn" activity, where teams used bicycle inner tubes to move a can of popcorn from the middle of a large circle without entering the circle. Using these activities created an environment where teachers felt comfortable fully participating in the discussions and activities. Everyone participated in a needs assessment surrounding the question, "Why are we here?" The methods that engineers, scientists, teachers and students use to solve problems were discussed. This led to discussion on the preparation of a Design Brief as a detailed statement of the problem, the constraints, and its relationship to classroom activities.

As a means of teaching the participants how to design their own experiments, Mr. Dearing presented a series of design problems for use during the Institute. Table 2 provides a brief description of these presenter-prepared design problems. Those marked with an asterisk (*) were used during the Institute; those that are unmarked were not used during the Institute, but were made available to the participants. One example of a hands-on design problem that was used relatively early in the Institute is the activity entitled Rapid Transit. The teachers enjoyed devising a vehicle capable of traveling in a straight line while carrying a 10 penny payload for a distance of 20 feet. An interesting observation by the authors was that, at this point, the teachers were mostly using a trial-and-error method for problem solving, and would immediately begin building rather that thinking the problem through and creating a plan first. Their methodology for solution got better as the workshop progressed (bringing books to the workshops, using the web to look up information, and thought about how to tackle the problem before diving in and building). After each design problem, the entire group analyzed the different designs. Through led discussion, the design activities were tied to the Arkansas Curriculum Frameworks for each grade level.

Table 2. Description of Presenter-prepared Design Activities

Activity	Description
Rapid Transit*	Develop vehicle that carries 10 pennies distance of 20 ft, straight line
Buoyancy*	Illustration of Newton's Laws of Motion
Road Rash	Identify problems with a prototype that was rushed through R&D
Let's Get Moving	Illustration of Newton's Third Law of Motion
Turn on the Light	Troubleshoot a flashlight that doesn't work
Spilt Milk	Why and how defective "sippy-cups" leak
You've Got Mail	Wheelchair access to a mailbox
Alien with Attitude*	Shoot an alien (NERF ball) with a projectile (golf ball), distance of 3 ft
Mechanical Marvel*	Create a toy that uses a mechanical engine
Volunteers*	Develop operating procedures for a selected task
Make it Rain	Design and construct prototype condensation device
Spinning Wheels*	Construct spinning device that remains in motion for 6 min

*used in hands-on small groups during Institute

Beginning on Day 5 of the Institute, the focus shifted from presenter-prepared design activities to the preparation of design briefs and activities which were of particular interest to the participants. The shift to participant-motivated design activities was the perfect time for the participants to develop an open-ended design activity on a subject that was not previously illustrated very well in their classrooms.

Participants were placed in groups of two (same grade level) and asked to prepare design briefs for one or more open-ended design experiments, including the statement of the problem, introduction and rationale; a materials list; the relationship of the experiment to what the students are studying; general directions for completing the exercise; parameters or limitations in the design; how the students will be evaluated; and how the experiment relates to the Arkansas Science Frameworks.

Table 3 provides a listing and description of the participant-developed design experiments; some were very open-ended design-oriented experiments, and some fell a somewhat short of that goal. This likely reflects the participants' current state in understanding the design process. Some groups created two design activities and others struggled to prepare one.

Table 3. Description of Participant-prepared Design Activities

Activity	Description
Beak Builder Blowout	Structural adaptation in species
Comparing Soil Composition	Soil composition as a diagnostic tool
Cooking with Energy	Developing a solar heater
Wilderness Adventure Turns Deadly	Solubility as a diagnostic tool
To Launch or Not to Launch	Building and testing an anemometer
Earthquake Table	Building an earthquake simulator
Junk Yard Blues	Designing and testing an electromagnet
Keeping your Cool	Conduction, convection and radiation
Classroom Band	Construct/demonstrate a musical instrument
Natural Gas	Locate gas deposits and relate to land forms
Rube Goldberg Machine	Maximize steps in performing a task
Salt for Sale	Separating mixtures
Save an Egg/Save a Life	Modified egg drop
The Digestive System	Model/skit on digestive system
Solar System Model	Model the solar system with size and distance
Solar Pioneers	Prototype to protect against UV light
Water, Water Everywhere	Separating mixtures
Whole Lotta Shakin'	Earthquake warning device

As an example of these activities, consider the activity entitled "Beak Builder Blowout". This activity was designed for 6th graders, inviting them to investigate structural adaptation in species of birds. Since all living things must interact within their ecosystem to meet their basic needs, all species have structural adaptations that make them best suited for a specific environment. The scenario begins when a bird species has lost its food source due to environmental factors. A new food source is available, but the birds do not have the structural adaptations needed to retrieve the food. The students represent a team of genetic engineers who must create a prototype of a bird beak that can help the bird survive. The bird's only food will be a type of worm that lives in sand, and the bird must have a way of getting the worms out of the sand. The students must construct various beak types from a list of materials and then test their suitability in removing gummy worms from sand. After the completion of the experiment and demonstrations by each team, the students are given a summary questionnaire that evaluates their understanding of what their team and each other team did. Evaluation of the students is based on their design plan, teamwork, creativity and workability of the designs.

Evaluation

The success of the program is being measured by the performance of participating teachers and their students on standardized assessment tests, and by teacher evaluation of the workshop experiments. The teacher assessment was developed at the University of Louisville, Center for

Research in Mathematics and Science Teacher Development, and is administered both at the beginning and at the end of each workshop. Students are tested each spring using the Iowa Test of Basic Skills (ITBS) as an assessment of student performance, as part of the State's required accountability testing system. Assessment results from the Year 2 Institute were not yet available at the time this manuscript was prepared.

Selected results from the daily teacher evaluation surveys are presented in Table 4. As is noted, the participants became comfortable with the design brief approach relatively early in the Institute, and became comfortable with the development of design briefs for their classes by the end of the Institute. The teachers were a bit less comfortable in replacing a trial-and-error procedure with a systematic approach in solving design problems.

Table 4. Teacher Perceptions of Learning Outcomes of the Institute

I know the similarities and differences between the methods scientists and engineers use to solve problems	4.4 (2)
The opportunity to choose an activity that was of interest to me was helpful in broadening my experiences with design briefs	4.4 (2)
I know the difference between a design brief activity and a typical lab experiment	4.6 (4)
Presenter-prepared design brief activities helped me to develop my own design brief	4.5 (5)
It was easy to correlate my design brief activity to grade-level frameworks	4.5 (5)
The design brief activity that my small group performed today was design-related, rather than experiment-related	4.7 (7)
When my small group first reviewed the selected design brief for today's activity, we worked through the design loop process rather than employing trial and error	3.9 (7)
My attitudes regarding implementation of design brief activities into my classroom have changed during the Summer Institute	4.7 (9)
I am less concerned about how problem-solving design will affect my students than I was at the beginning of the Summer Institute	4.4 (9)
I am less concerned about how I will find time to develop design brief activities than I was at the beginning of the Summer Institute	4.3 (9)

Day of survey is in parentheses; 5—strongly agree, 1—strongly disagree

Follow-up Activities

Classroom Visitation

Another goal of the Institute was to have university professors and other personnel interact with teachers, both during the Institute and afterwards in their classrooms, during the academic year. In the 2007-2008 school year, 22 classroom visits were made by university personnel to 19 different teachers. Six of the teachers were visited twice and two of the teachers were visited three times. Eighteen of the visits were scheduled to observe classroom design activities, three of the visits were scheduled to make classroom/multi-classroom presentations by representatives of the university, and one of the visits was scheduled just to talk briefly with the teacher about her use of design activities. An average visit included two visitors, but eight of the visits included only one visitor and one of the visits (a Parents' Night activity) included seven visitors. Of the eight U of A classroom visitors, seven were from the College of Engineering (five faculty members, two students), two were representatives from the College of Education and one was a Physics graduate student.

Use and Development of Design Activities

The real measure of the Institute's success is the effective use of the activities by teachers in the classroom. Table 5 shows a summary of the 2007-2008 implementation of the teacher-designed activities, as reported on surveys collected throughout the school year. Twenty-one teachers responded to the survey. The activities are categorized as icebreakers, or short activities designed to build teamwork; presenter-prepared design activities; design activities that were developed by the teacher groups at the Institute; and design activities that were developed by teachers after the Institute. As is seen in Table 5, 34 icebreaker activities were used by the 21 teachers for an average of 1.6 icebreakers used per teacher. Four teachers chose not to use icebreakers, and one teacher used four icebreakers. Nineteen presenter-prepared design activities were used by the 21 teachers for an average of 0.9 presenter-prepared design activities per teacher. Eight of the teachers chose not to use presenter-prepared design activities, and two teachers used three presenter-prepared design activities. The effectiveness of the workshop is clear, as demonstrated by 73 teacher-developed design activities used by the 21 teachers for an average of 3-4 teacher-developed design activities per teacher. Use of the teacher-designed activities developed during the Institute ranged from three of the teachers choosing not to implement any of the activities to one teacher using seven activities. Best of all, 19 new design activities were developed by the teachers after the Institute, with development ranging from three teachers developing no new activities to one teacher developing six new activities for the classroom.

Table 5. 2007-2008 Teacher Use of Institute Activities

Institute Activities	**Activity Use per Teacher**		
	Minimum	**Average**	**Maximum**
Icebreakers	0 (4)	1.6	4 (1)
Design Activities presented at Workshop	0 (8)	0.9	3 (2)
Design Activities developed by teachers at Workshop	1 (3)	3.5	7 (1)
Newly developed Design Activities	0 (3)	1.6	6 (1)

21 teachers surveyed

Year 3 Institute Plans

Following a very successful Year 2 Institute and follow-up activities, sweeping changes in the Year 3 Institute are not warranted. However, a few changes will make the Year 3 Institute even better:

- Many students (and teachers) initially use a trial-and-error approach in solving open-ended design problems. The Year 3 Institute could teach participants how to truly implement the "design loop" in their classrooms as a systematic approach to solving problems.
- Additional U of A faculty will participate in the Institute and be available for follow-up activities during the academic year, thereby providing additional resources for the teachers.
- Several middle school math teachers are excited about participating in the Year 3 Institute. Adding mathematics content to the science-based Institute will aid teachers in design brief development that incorporates both science and mathematics frameworks.

To further expand on these changes, one focus of the Year 3 Institute will be to better utilize the "design loop" in helping teachers move students away from trial-and-error and toward a systematic approach in solving open-ended problems. The Year 2 Institute showed that with instruction and practice, the teachers were capable of making this transition. Similarly, students should be capable of making this same transition with appropriate instruction and practice.

To help develop more faculty-teacher interaction, six additional engineering faculty members and one mathematics faculty member will be added to the Year 3 Institute and follow-up staff. The Engineering faculty were selected to provide background and suggestions in the topical areas of the Year 2 teacher-prepared design briefs shown in Table 3. These areas (including life science, soils, weather, separations, solubility, physics and space) were identified as areas that the teachers felt were not previously illustrated very well in their classrooms. The mathematics faculty member will provide assistance in incorporating middle school mathematics into the design briefs, and will also serve as a resource in developing a proposal for continuations of the summer Institutes.

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