UAESP: A New and Improved Program for Helping Middle School Teachers Devise Their Own Hands-on Engineering and Science Activities

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Abstract

The University of Arkansas Science and Engineering Partnership (UAESP) was developed in 2009 to enhance the professional growth of 6th and 7th grade science teachers in northwest Arkansas through summer workshops, mini-workshops and follow-up activities. Major features of the program, which impacts the teaching of more than 3,800 students, include:

- Design-based, teacher-developed, hands-on activities that directly align with science frameworks mandated by the State of Arkansas
- Direct involvement of engineering professors to enhance teacher-content knowledge
- Teacher visitation to observe the use of workshop content/techniques in the classroom
- Assessment of the impact of the program on student and teacher performance

During the 2009 summer workshop, the 41 middle school teachers participating in the program developed 21 new physical science activities for their classrooms. Activity use surveys showed that each teacher, on average, used 2.8 of these activities in the classroom during the past school year. Perhaps more importantly, the teachers developed an average of 1.1 new activities for classroom use by applying the concepts presented in the workshop. Student test scores on the *Science Process Assessment for Middle School Students* improved by 0.36 SD units from pre-test to post-test, the equivalent of moving an individual from the 50th percentile to the 64th percentile in a normal distribution. Average 7th grade student science test scores on the *Stanford Achievement Test* were six percentage points higher for students of UAESP teachers than students from matched schools. Although teacher test scores in both knowledge and content improved slightly from pre-test to post-test, the results were not statistically significant.

Introduction

The National Science Foundation has recognized the need to introduce students to engineering and science at an early age to increase the number of students entering the engineering discipline. However, most students in the middle level grades (6th and 7th) are unaware of opportunities in engineering and do not recognize engineering as a rewarding career option. Eighth grade is a critical coursework juncture, when students and parents choose whether or not the student will participate in the math and science series. Actions during this critical juncture largely determine engineering readiness upon high school graduation. Furthermore, research tells us that women and minority students are drastically underrepresented in the engineering field.[1] To more effectively prepare students for engineering and science degrees, K-12 students need to be engaged in activities which 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. However, 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 (U of A) formed the University of Arkansas Science Partnership Program (UASPP), with funding from the Arkansas Department of Higher Education. Partnering with the Northwest Arkansas Education Renewal Zone (NWA-ERZ), middle school students were engaged in hands-on, standards-based science activities.[5] In 2009, a new grant was funded, the University of Arkansas Engineering and Science Partnership (UAESP), with funding from the Arkansas Department of Education. This grant built on successful components from the earlier grant. This UAESP program focuses on the professional growth of 6th and 7th grade science teachers from 22 partner schools in the NWA-ERZ. The program annually holds a six-day summer workshop, four mini-workshops held during the school year and follow-up activities. Major features of the program, which impacts the teaching of more than 3,800 students in northwest Arkansas, include:

- Design-based, teacher-developed, hands-on activities that directly align with science frameworks mandated by the State of Arkansas
- Direct involvement of engineering professors in enhancing teacher-content knowledge
- Teacher visitation to observe the use of workshop content/techniques in the classroom
- Assessment of the impact of the program on student and teacher performance

The purpose of this paper is to describe the organization of the UAESP program and its content, and to summarize developments and educational results from the first year of the program.

Program Development and Content

To initiate the UAESP program, a needs assessment survey was sent to middle school science teachers from the 22 partner schools in the NWA-ERZ. The assessment showed that 100% of the respondents taught in the academic subject and grade level for which they were trained and licensed, and therefore met the State’s definition of a highly-qualified teacher. Of the 22 partner schools, 21 had 25% or more students on free or reduced lunch, and 12 of the 21 schools also had the “school in improvement” designation. The Springdale School District (just north of the U of A) is now 60% Hispanic and has the second largest Marshallese population in the world (second to the Republic of the Marshall Islands). The Rogers School District (just north of Springdale) also has a large Hispanic population. Largely due to the success of the earlier UASPP, more than seventy-five 6-8th grade science teachers submitted assessment responses and agreed to participate in this program, if funded. Funding from the State limited the program to 41 teachers; thus, it was decided to limit the program to 6th and 7th grade teachers because of similarities in science frameworks in these grade levels. Twenty 6th grade teachers and twenty-one 7th grade teachers from 17 middle schools participated in the program in 2009.

The focus of the UAESP program in Year 1 was physical science, and specifically the areas of energy and chemical mixtures/separations. State benchmark student test scores showed that 7th graders in northwest Arkansas (as well as the entire State of Arkansas) correctly answered only

50% of the Physical Science multiple-choice questions and 25% of the Physical Science open-response questions (20 percentage points lower than the next lowest strand). The two lowest subscores within Physical Science were energy and chemical mixtures/separations. While teachers may feel prepared to teach physical science concepts, they may be lacking in confidence or content knowledge in these areas, which unfortunately transfers to their students.

Engineering professors were recruited to work with teachers on content knowledge and hands-on activities for the classroom. Expertise in a given subject area was not a significant factor in selecting professors for the program; any engineering faculty member with a PhD is capable of teaching any middle school science topic. Instead, interest and enthusiasm were the key factors in selection. The professors were given middle school science textbooks prior to their participation in the workshop, as well as the directive to increase teacher content knowledge, but not to aim too high. Eight Engineering professors participated in the workshop.

Workshop Content

Table 1 shows a summary of the daily activities from the six day (Monday-Saturday) summer workshop. The workshop began on Day 1 with introductions of staff and teachers, and an overview of the purpose of the workshop. The teachers were then given the physical science form of a workshop pre-test entitled *Diagnostic Science Assessments for Middle School Teachers*,[6] a test designed to describe the breadth and depth of science content knowledge so that evaluators can determine teacher knowledge growth over time. The same test was given to teachers as a post-test at the last mini-workshop in May 2010 to assess teacher improvement in the target subjects throughout the school year. After the pre-test, the workshop continued with an ice-breaker and instruction on the hands-on design brief learning style from the textbook *Understanding by Design*, 2nd edition, by Wiggins and McTighe.[7] The primary focus of this instruction was the design loop method of solving design-oriented problems, design brief preparation, application of these principles in the classroom, and a number of design-oriented activities which fit well with the State-mandated science frameworks. Workshop evaluation/assessment was the final activity of each day.

Table 1. Activities from the Year 1 Summer Workshop

Day	Content
1	Introductions; workshop overview; diagnostic pre-test for teachers; ice-breaker; hands-on design loop learning style; selection of small group frameworks topics; daily workshop evaluations/assessments
2	Ice-breaker; initial hands-on experiment; more complex hands-on experiment; discussion of the methodology used to solve problems; teachers explore supplies, tools; introduce small groups and activities; daily workshop evaluations/assessments
3	Faculty introductions; U of A Engineering faculty provided deeper content knowledge through discussion/interaction in small learning groups; teacher subgroups develop design briefs and experiments; subgroups select another subgroup to run experiment and critique the design brief and experiment; daily workshop evaluations/assessments
4	Subgroups share each experiment with entire group; repeat Day 3 activities with other faculty/emphasis areas; daily workshop evaluations/assessments
5	Finish Day 4 activities; daily workshop evaluations/assessments

6	Announcements; school year activities; general workshop discussion; daily workshop evaluations/assessments

Day 2 began with another ice-breaker, and then quickly moved to the teachers solving a hands-on experiment, “There’s Iron in Cereal?”, a simple solids separation experiment that involved recovering iron particles from breakfast cereals. After a brief discussion of the methods used in solving this experiment, the teachers then solved a more complicated solids separation experiment, “Separating Complex Mixtures of Solids” (iron filings, salt, pepper, sand), which required more organization and creativity in solving the problem. The teachers were reminded that although one purpose of the workshop was to help the teachers develop their own hands-on, design based experiments, another purpose was to show teachers (and, later the teachers show their students) the methods for solving complex problems/experiments. After providing time for the teachers to explore workshop supplies and tools (a typical worker’s toolbox and a 2ft x 3ft x 2ft Rubbermaid™ box containing tools and miscellaneous supplies that can be used in a variety of hands-on activities), the teachers were introduced to the areas of emphasis for small group activity.

Day 3 began with faculty introductions and the areas for small learning group emphasis:

- Energy, Energy Forms and Transformations—Frameworks 7.6.1-7.6.3, 7.7.3
- Energy and Fossil Fuels/Alternative Energy Sources—Frameworks 7.7.1, 7.7.2, 7.7.4
- Solubility—Frameworks 5.7.7-5.7.9
- Heat Transfer—Framework 7.6.4
- Chemical Properties and Changes—Frameworks 5.6.1-5.6.8 and 5.7.1-5.7.4
- Forming and Separating Mixtures—Framework 5.7.5

Learning groups were formed for the first three emphasis areas, with faculty providing deeper content knowledge through discussion/interaction. Emphasis was placed on the development of hands-on, design based experiments (with faculty assistance), alignment with State-mandated science frameworks and opportunities for adding math content. Experiments such as a “Top Chef” competition for creating a new snack food (using convection, conduction, radiation) and a Lifesaver™ solubility experiment were created. After the teacher subgroups finished preparing and testing the experiments, they had another subgroup perform and critique the design brief and experiment. Days 4 and 5 were used to repeat this procedure with the three remaining emphasis areas. At the conclusion of these activities, the teacher subgroups presented all of the newly developed design briefs to the entire group of participants, and a file containing all of the design briefs was given to each participant. Twenty-one new design briefs/experiments were developed by the participants. Day 6 was used to make plans for mini-workshops and teacher visitation, and to discuss the workshop as a whole.

Mini-workshops

One day mini-workshops were held in October, December, February and May of the academic year. The emphasis of each of the mini-workshops is detailed in Table 2. These mini-workshops included presentations of design activities (and associated problems) by the teachers, research presentations by professors, a new design experiment, and presentations and methods for enhancing student productivity in the classroom. The teacher post-test was given during the May mini-workshop.

Table 2. Mini-workshop Emphases

Mini-Workshop	Emphasis
October	Pre-test summary; teacher presentations of hands-on experiments; mini-courses in chemical properties and changes and earthquakes
December	Teacher presentations of new design briefs/experiments; mini-course in biomedical engineering/women and minorities in engineering
February	Use of whiteboards in the classroom; chemical reaction powered car exercise; Gizmos
May	Post-test; vocabulary use; teacher presentations of challenges with design briefs/experiments

Follow-up Activities

One measure of the success of the program is the use of the workshop activities by the teachers in the classroom. U of A faculty and staff visited the teachers to observe student use of workshop activities in the classroom, make classroom or multi-classroom presentations or participate in Science Night activities. *All* of the teachers participating in the workshop were visited by faculty/staff at least once during the academic year. A total of 48 visits were made, and 12 U of A faculty/staff participated in the visits.

Table 3 shows a summary of the use of design activities by the teachers, as reported on teacher surveys. The activities are categorized as design activities that were presented by the moderators at the workshop or mini-workshops, design activities from previous UASPP workshops, design activities that were developed by the teacher groups at the summer workshop, and design activities that were developed by the teachers after the workshop. The three moderator-developed design activities ("There's Iron in Cereal?", "Separating Complex Mixtures of Solids" and the "Chemical Reaction Powered Car") were used 24 times by the 37 teachers that were surveyed, for an average of 0.6 moderator-developed activities per teacher. The numbers in parentheses in Table 3 represent the number of teachers using a particular type of activity. For example, 19 of the teachers chose not to use moderator-developed activities in their classrooms, and one of the teachers used all three moderator-developed activities. Design activities from the three previous UASPP workshops were used 28 times by the 37 teachers, for an average of 0.8 UAESP workshop-developed activities per teacher. The 21 activities developed by the teachers at the 2009 UAESP summer workshop were used 105 times by the 37 teachers, for an average of 2.8 activities per teacher. Twenty-four activities were either developed by the teachers after the summer workshop or modified from experiments they found elsewhere. These teacher-developed activities were used 40 times by the 37 teachers, for an average of 1.1 activities per teacher. Overall, only one teacher did not use any design-oriented activities (taught math in 2009-2010, instead of science), and one teacher used 14 activities. The teachers were most active in using activities that they developed, and in using workshop techniques in developing additional activities. This shows that it is more effective to teach the participants "how to fish (develop hands-on experiments)" instead of "providing fish (providing hands-on experiments)" for the participants.

Table 3. Teacher Use of Workshop Activities, 2009-2010

Workshop Activities	Activity Use per Teacher		
	Minimum	Average	Maximum
Design activities presented at 2009 Workshop and Mini-workshops, sometimes with modifications	0 (19)	0.6	3 (1)
Design activities from previous UASPP Workshops, sometimes with modifications	0 (20)	0.8	3 (3)
Design activities developed by teachers at Workshop, sometimes with modifications	0 (3)	2.8	7 (1)
Newly developed design activities, sometimes by others or with modifications	0 (17)	1.1	4 (2)

37 teachers participated in the survey
Numbers in parentheses indicate the number of teacher participants using an activity

Student/Teacher Testing

To measure the success of the UAESP program, the effect of the program on teacher and student performance must be assessed. As was noted earlier, the physical science form of *Diagnostic Science Assessments for Middle School Teachers*[6] was used as both a pre-test (prior to the beginning of the workshop) and post-test (end of the school year) for the teachers. This test was designed to describe the breadth and depth of science content knowledge so that evaluators can determine teacher knowledge growth over time. Student participants were given *Science Process Assessment for Middle School Students,*[8] a reliable and valid test that was written specifically for middle school students and focuses on processes rather than isolated facts. As with the teachers, the same test was given pre-test (beginning of the school year) and post-test (end of the school year). Finally, all 7th grade students are required by the State to take the *Augmented Benchmark Examinations*,[9, 10] which includes the *Stanford Achievement Test*, *version 10* (SAT-10) and tests reading, math, writing and science.

Science Process Assessment for Middle School Students

Student testing on the *Science Process Assessment for Middle School Students* involved a two-step process: 1) testing the students in the classroom, and 2) securing permission from the parent/guardian to use the result in the analysis of the UAESP program. A total of 3,553 students took the pre-test, but only 2,873 had signed consent forms from the parent/guardian. A total of 3,378 students also took the post-test but, once again, only 2,530 students had signed parent/guardian consent forms. Thus, student testing was based on the 2,530 students that took both the pre- and post-tests and also had parent/guardian consent.

Results from the student testing are shown in Table 4. Thirteen process skills were evaluated, with 2-7 questions asked per process skill. The percentages of correct answers for both the pre- and post-tests are shown. Also shown are the effect size and the scale reliability. Effect size expresses group differences in standard deviation (SD) units. Cohen[11] states that 0.20 SD units represents a small effect, 0.50 represents a medium effect and 0.80 represents a large effect. As an example, consider ACT scores with SD = 5, where a 4 point difference is a large effect. An ACT increase from 25 to 29 is a big deal, and the effect size = (29-25)/5 = 0.80. For SAT scores with SD = 100, a four point difference is a tiny effect. Increasing the SAT score from 550 to 554 is no big deal, and the effect size = (554-550)/100 = 0.04. Effect size does not depend on sample size.

Statistical significance depends both on effect size and sample size. Because the UAESP student test data represent a large sample, small differences are significant. The effect size on the total average score from Table 4 was 0.36. According to a normal curve table, a 0.36 SD increase is equivalent to moving an individual in a normal distribution from the 50th percentile to the 64th percentile.

When items are combined together to report a single score, it is preferable that the items are "going in the same direction". Reliability is a number ranging from 0 to 1. Zero reliability means that the items are unrelated, and a reliability of one means that all of the items are asking the same question. The total reliability of 0.88 shown in Table 4 is an excellent level, suggesting that the total score is a good representation of the 50 items making up the test. The subscales have fewer items and thus lower reliabilities. There is less confidence in the accuracy of the subscale scores than in the accuracy of the total score.

Table 4. Results from *Science Process Assessment for Middle School Students*

Science Process Skill	Average % Correct		Effect Size	Scale Reliability
	Pre-test	Post-test		
Observation	81.92	87.88	0.29	0.12
Classification	66.61	74.82	0.34	0.35
Inferring	83.84	90.00	0.31	0.45
Prediction	78.26	83.09	0.22	0.33
Measuring	71.64	76.88	0.26	0.39
Communicating	78.70	80.20	0.09	0.53
Using Space/Time Relations	71.82	76.13	0.19	0.42
Defining Operationally	70.93	77.41	0.26	0.46
Formulating Hypotheses	59.49	66.75	0.22	0.37
Experimenting	72.77	77.18	0.26	0.70
Recognizing Variables	66.22	71.30	0.24	0.50
Interpreting Data	71.85	76.23	0.25	0.66
Formulating Models	72.61	77.39	0.28	0.58
Total	**73.76**	**78.90**	**0.36**	**0.88**

2,530 students tested

The goal of the first year of the UAESP program was an effect size gain of 0.25 SD units with statistical significance. Table 4 shows that the program exceeded this goal, with an effect size of 0.36 SD units and statistical significance for all science process skills. The only skill showing a marginal gain in effect size was “Communicating”, which the UAESP program coordinators feel contained a question that was wrong on the answer key. Although significant improvements were made by the students from pre-test to post-test, it must be realized that hands-on activities in conjunction with other classroom activities and instruction are responsible for the improvement.

Augmented Benchmark Examinations

Although all 7th grade students in the State of Arkansas are required to take the *Augmented Benchmark Examinations*, test results are most meaningful to the program if UAESP students are compared to students from similar schools from around the state. Schools with teachers in the UAESP program were "matched" with other schools in the state based on 2009 7th grade *Augmented Benchmark Examination* scaled science scores. Since the State of Arkansas only tests 7th graders in these benchmark exams, the UAESP group was limited to the ten schools with 7th grade teacher participants. Eight of the ten "match" schools were an exact match with the UAESP schools, while two of the ten differed by only one point, with scaled science scores ranging from 166 to 212. When several candidate schools had scores that were equally close to a UAESP score, the number of students taking the test was used as the secondary selection criterion. Paired sample *t* tests confirmed that at pretest there were no significant differences between the matched schools in benchmark science scores, number of students taking the test and percent free/reduced lunch.

Table 5 shows test results from the science sections of the 2010 *Augmented Benchmark Examinations* for both the UAESP and match groups. Also shown with the scores are the standard deviation, *t*-test results, statistical significance (p) and effect size (d). The goal of the first year of the UAESP program was an effect size gain of 0.25 SD units and statistical significance ($p < 0.05$). If $t_{df=9}$ is greater than 2.26 (for this sample size) and p is less than 0.05, the scores are statistically significant. As noted earlier, an effect size of 0.80 or above represents a large effect.[10] Scores on the SAT-10 science test were reported as the national percentile rank of the mean that shows how each school did in comparison to the rest of the country. The UAESP mean of 76.5 was significantly higher than the mean of the matched schools (70.3) ($t_{df = 9} = 2.703$, $p = 0.02$, $d = 0.93$). This result is particularly impressive, given the small sample size of only ten matched schools.

Table 5. Results from 2010 *Augmented Benchmark Examinations* in Science

Test	Mean	Standard Deviation	$t_{df=9}$	p	Effect Size, d
SAT-10, National Percentile Rank					
UAESP Schools	76.5%	5.6	2.70	0.024	0.93
Match Schools	70.3%	7.7			
Mean Benchmark Scaled Score					
UAESP Schools	193.2	11.9	1.34	0.212	0.45
Match Schools	187.1	14.7			
Benchmark, % Proficient/Advanced					
UAESP Schools	49.3%	10.6	1.72	0.119	0.61
Match Schools	41.7%	13.9			

Ten pairs of schools participated, N = 10
$t_{df = 9} > 2.26$ and p < 0.05 to be statistically significant

The benchmark scaled scores ranged from 168 to 213 for the sample. The UAESP schools had a mean score of 193.2 and the match schools had a mean of 187.1, but the difference was not statistically significant ($t_{df=9} = 1.34$, $p = 0.21$, $d = 0.45$). Benchmark scores were further categorized as advanced (a scaled score of 250 or above), proficient (200-250), basic (154-200) or below basic (<154). The percentage of students classified as proficient or advanced was compared for the UAESP and match schools. The UAESP schools averaged 49.3% proficient or advanced, and the match schools averaged 41.7%. However, the difference was not statistically significant ($t_{df=9} = 1.72$, $p = 0.12$, $d = 0.61$). It is worth noting that the data of Table 5 all showed at least a medium effect based on Cohen's standard of 0.50 SD units for a medium effect.[11] Statistical significance was limited by the sample size of only ten pairs of matched schools.

Teacher Testing

Teacher test results in the form of teacher pre- and post-test scores and effect size are shown in Table 6. The teachers were tested on their knowledge and content in multiple areas using a test battery of 20 multiple-choice and 5 open-response questions. Knowledge was divided into four areas:

- Declarative knowledge, or the knowledge of definitions and facts
- Scientific inquiry and procedures, or the knowledge of scientific procedures and approaches
- Schematic knowledge, or a deep understanding of science concepts, laws, theories, principles, and rules
- Pedagogical content knowledge, or strategic knowledge for science teaching

Content refers to the basic understanding of physical science concepts in the areas of matter, motion and forces, and energy.

Once again, the goal of the first year of the UAESP program was an effect size gain of 0.25 SD units and statistical significance ($p < 0.05$). Table 6 shows that the goal was met for "Declarative Knowledge" and "Pedagogy Knowledge", with effect sizes of 1.18 and 0.29, respectively, and $p < 0.05$. The effect size goal of 0.25 SD units was met for "Motion and Force Content" (0.36), but the result was not significant ($p = 0.11$). Two subscores ("Science Inquiry Knowledge" and "Science, Technology and Society") showed statistically significant declines (shown as negative gains) from pre-test to post-test. "Total Knowledge" and "Total Content" both increased from pre-test to post-test, but neither was statistically significant ($p = 0.10$ and $p = 0.47$, respectively).

Table 6. Results from Teacher Pre- and Post-tests

Scale	Maximum Score	Mean Score		Gain	Effect Size
		Pre-test	Post-test		
Knowledge					
Declarative, or knowledge of definitions and facts	5	3.22	4.22	1.00*	1.18
Science Inquiry, or knowledge of scientific procedures and approaches	5	3.61	3.06	-0.55*	-0.46
Schematic, or a deep understanding	15	8.19	8.08	-0.11	-0.04

of science concepts, laws, theories, principles and rules					
Pedagogy, or strategic knowledge for science teaching	16	2.36	3.14	0.78*	0.29
Total	35	17.39	18.50	1.11	0.18
Content					
Matter	6	4.53	4.39	-0.14	-0.11
Motion and Forces	6	3.47	3.89	0.42	0.36
Energy	13	7.03	7.08	0.05	0.02
Total	25	15.03	15.36	0.33	0.09
Science, Technology, Society	5	2.89	2.33	-0.56*	-0.48

*$p < 0.05$
A negative gain is a decline from pre-test to post-test

Suggestions for Program Improvements

The middle school workshop and follow-up activities have improved in each of the five years the UASPP and UAESP programs have existed. Although the UAESP program is effectively satisfying the needs of middle school science teachers in northwest Arkansas, there are areas for improvement in future workshops and related activities:

- In forming the professor-led small learning groups for the 2010 workshop, we will separate the 6th and 7th grade teachers by grade level. Although the State-mandated science frameworks are very similar for these two grades, the teachers view the frameworks as being very specific concepts for their classrooms and are not generally interested in frameworks for the "other" grade level. Thus, an equal number of separate 6th and 7th grade learning groups are needed at each workshop.
- As expected, some professors were better than others in providing teacher content knowledge and inspiring the development of hands-on activities. More care will be taken in selecting professors for workshop participation, and more "training" will be given to professors prior to the workshop. To maximize the effectiveness of the professors, an effort will be made to limit the scope of the workshops topics.

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