

BRIDGES WITH ENGINEERING TO TEACH AUTHENTIC INQUIRY-BASED MATHEMATICS AND SCIENCE COURSES TO MIDDLE AND HIGH SCHOOL STUDENTS

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Abstract -- *The paper presents the development and implementation of National Science Foundation funded GK-12 Fellows Project STEP, which is designed to educate, nurture, and facilitate engineering, and science and technology education university students (ten graduates and three undergraduates) into becoming educators and bringing their experiences and knowledge into six secondary schools in Cincinnati. Seven University of Cincinnati (UC) faculty members, fifteen secondary school teachers, and a dedicated graphics/web developer have worked in teams with the graduate and undergraduate fellows to design, develop, and implement hands-on activities and technology-driven inquiry-based projects, which relate to the students' community issues, as vehicles to authentically teach STEM skills. The Fellows are trained to create and implement these activities by taking a new education course, and field practicum. The paper presents how the project has evolved over the first year, the activities developed and implemented, and the findings from the whole experience.*

INTRODUCTION

The shortage of qualified K-12 teachers is a looming educational crisis. Contributing factors are an aging workforce, low salaries, increasing student enrollment, and increased competition for jobs. Teachers' need is projected to rise from 2.96 million in 1994 to 3.43 million by 2006. Student enrollment is expected to increase from 49.8 million in 1994 to 51.3 million by 2006 (Gerald and Hussar, 1996). Approximately 24% of elementary teachers and 26% of secondary teachers are expected to retire in the next 12 to 15 years (Bandeira de Mello and Broughman, 1996). A national survey conducted by the American Association for Employment in Education reported immediate needs for math (95%), science (98%), and special education teachers (98%) in urban school districts. The availability of alternative lucrative jobs has presented a challenge to school administrators to recruit and retain new teachers. At the same time, recent surveys (in Public Agenda, 2000) reveal that compared to recent college graduates working in other

professions, 96% new teachers report higher job satisfaction and more job security.

Fewer than half of all math teachers in the U.S. have a major or minor in math, and 28% of math teachers (and 18% of science teachers) lack state certification in their field. This shortage comes at a time when the expectations for what students should know in math and science are rising (National Council on Teacher Quality, 2001). This trend is most troubling in light of the recent quantitative research by Darling-Hammond (2000) indicating "that measures of teaching preparation and certification are by far the strongest correlates of student achievement in reading and mathematics, both before and after controlling for student poverty and language status." For too long, schools of education have been allowed to train teachers and administrators who sometimes are more interested in teaching in ways that feel good, or are fun, than those that actually result in solid learning (Larson, 2001).

Thus, we proposed to the National Science Foundation (NSF) the *Project STEP - Science and Technology Enhancement Program* to educate, nurture, and facilitate science and technology university students into bringing their experiences and knowledge into the classroom and becoming educators. Additionally, project STEP recognizes that effective science and math education requires authentic and inquiry-based learning. Students must be able to link the relevance of their education with events and issues occurring within their community. They must be able to experience how it allows them to participate as effective citizens in a technology-driven society. This paper presents the development and implementation of this project over the first year (July 2002 to June 2003). The project is expected to continue for two additional years, and then will be up for renewal. Thus, if successful it will be a long-term project, and, as such, can have a significant impact.

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**RESEARCH AND EDUCATION ACTIVITIES
PLANNED FOR THE PROJECT**

The major activities of Project STEP include training graduate and undergraduate fellows in engineering and education to work in science and math classrooms in six local public schools located in three different school districts. It involves nine graduate and three-advanced undergraduate fellows, fifteen secondary science and mathematics teachers (from one middle, two middle-high, and three high schools located in urban and sub-urban school districts of Cincinnati), seven UC faculty (from the College of Engineering and College of Education), and a dedicated graphics/web developer. One additional graduate fellow is assisting in conducting the evaluation and assessment of the project activities.

The teachers and fellows work in teams to design, develop, and implement hands-on activities and technology-driven inquiry-based projects, which relate to the students' community issues, as vehicles to authentically teach STEM skills. Collaboration across teams is structured into the project. Activity themes for Civil Engineering will focus on: 1) innovations in construction materials, 2) civil infrastructure renewal, and 3) transportation for the future; and for Environmental Engineering and Science will focus on: 1) water cycle, 2) water quality, and 3) stream biology and ecology within the context of the river watershed.

Activities will be incorporated into lessons, demonstrations, laboratory exercises, individual and group projects, and field experiences to: 1) enable middle and high school students to directly experience authentic learning practices that requires them to use higher-order thinking skills; 2) encourage creative problem-solving skills that require collaborative learning, teamwork, writing, and presentation; 3) cultivate an interest in service learning, in which students are active participants, achieve outcomes that show a perceptible impact, and engage in evaluative reflection; and 4) better motivate and prepare secondary school students for advanced education. The Fellows have been and continue to be trained to create and implement these activities.

Through the course of the year, the fellows have completed a specially tailored educational methods course, two field placement courses, and will serve as teaching assistants and tutors in guiding summer academies for 4-12 grade students. The education courses trained them in: 1) methods, concepts, theory, and assessment of instruction; 2) design and implementation of science and mathematics curricula with an emphasis on instructional technology; and 3) local, state and national curriculum standards, educational practices, and pragmatic and logistical secondary education issues. The fellows will participate in an advanced instructional technology course during year two of the grant, which will train them in the use of electronic media for

curriculum and activity design, development, and effective delivery.

Quantitative formative and summative evaluation have been and will continue to be conducted to assess the project's effectiveness on Fellows' teaching skills and its impact on middle and high school science and mathematics education, and to continually improve the program as it develops.

**TRAINING AND DEVELOPMENT PROVIDED IN THE
PROJECT**

Through the inclusion of six schools located in three school districts, the fellows, faculty, and teachers had opportunities to benefit from interactions with different types of schools, teachers, and students. Six Cincinnati schools, with whom the University of Cincinnati College of Education has previously interacted, have been participating; they include: Amelia High School, Glen Este High School, Hughes Center (High School), Liberty Junior, Shroder Paideia (Middle-High), and Western Hills University High School. Amelia High School, Glen Este High School and Hughes Center are divided into small schools. At Amelia High School, the fellows worked with teachers and students from the Math, Science, and Technology School; at Glen Este High School, the fellows worked with teachers and students in the Scientific Studies School; and at Hughes Center the fellows worked with teachers and students in the Paideia School. The demographics for these schools are presented in Table 1, and following features should be noted: 1) mix of urban and sub-urban schools; 2) mix of 7-12 grades, 7-8 grades, and 9-12 grades in the same school; and 3) three schools contain a strong diversity of minority groups and three primarily have a homogenous white population. The mix of schools selected has provided, in addition to inter-age and inter-cultural exchanges among students (and their teachers), opportunities to compare the dynamics of student learning between groups from: 1) urban versus sub-urban; 2) primarily same race versus mixed race; 3) primarily minority versus white versus mixed; 4) homogenous socio-economic versus mixed socio economic group; and 5) long term impact in schools with 7-12 grades versus schools with 7-8 and/or 9-12 grades (particularly on motivating girls at a younger age).

OTHER COLLABORATORS IN THE PROJECT

In addition to the College of Engineering and the College of Education, Criminal Justice, and Human Services, and the K-12 schools, other organizations and businesses have supplied resources for the success of the grant goals. There are three collaborators, which are university based, the E3 Family Science Academy, the E3 Bridge program, and Women in Engineering program.

The E3 Family Science Academy will be working with the fellows throughout the summer. The academy is designed to provide 4-7 grade students and their parents with

hands-on experiences exploring fundamentals of physics and chemistry. For six weeks in the summer, the Academy is conducted on Saturday mornings from 9 a.m. to 12 noon. While the students conduct laboratory physics and chemistry activities, the parents engage in math and science activities that they duplicate with their children during the week at home. The fellows will work in the Academy as teaching assistants guiding the students through the experiments, and designing and testing new 'hands-on' activities for the upcoming school year. They will also develop and conduct a competition for the parent-child team.

The fellows will also be working with the E3 Bridge Program, which is an intensive six-week residential program designed to sharpen the academic skills of underrepresented ethnic students entering in the fall. During Bridge, students are enrolled in preview of calculus, physics, chemistry, and English that they will be taking in the fall. The fellows will act as teaching assistants in the classroom and tutors during the evening study sessions. Because the Bridge Program uses a cooperative learning teaching methodology, the fellows will be thoroughly trained in its use.

In addition to the work with the E3 projects, the grant also works, through corporate funding, with the Women in Engineering (WEI) program to encourage women students to seriously consider engineering as a career choice. Two 2-week summer camps are conducted for 150 students. The program incorporates three pre-collegiate phases: 1) Insights Into Engineering (6–8 grade), which focuses on problem solving skills and team projects; 2) Inquisitive Women (9–10 grade), which focuses on hands-on projects and seminars at UC, and field trips to view the opportunities available to women in engineering; and 3) Formulating Women in which students interact with women engineers from local industry, including many that hold management positions.

In addition to these university based programs, Messer Construction Co., College LiveText Edu Solutions, WCET48-TV, and Great Cities' Universities: Urban Educator Core serve as collaborators for the work of the grant. Messer Construction Co. sponsored several receptions including teacher meetings and the open house. College LiveText has provided online instructional activity design, collaboration, and standards alignment for the work of the grant. WCET48-TV has given verbal support to the work of the grant and we will continue to work with the television station as project-based learning activities are developed. The Great Cities' Universities: Urban Educator Core will financially support the work of the grant through the purchasing of laptop computers for the schools.

In addition to these groups, the Minorities in Math, Science, and Engineering group at Hughes Center has collaborated with a STEP fellow, as he has worked with them as an engineer to increase their enthusiasm for math, science, and engineering. The fellow has worked significantly with this after-school group and has made a significant contribution to the group this year.

PROJECT BASED LEARNING ACTIVITIES IMPLEMENTED IN THE FIRST YEAR (JULY 2002 TO JUNE 2003)

Our goal is to engage students and teachers at different grade levels to apply scientific concepts within a context-based learning environment. During the first year, teams were selected consisting of a fellow, secondary school teachers, and a UC faculty member. In some cases a graduate and an undergraduate fellow were paired, if they worked with either larger number of students or a larger number of teachers at a school. They have designed, developed, and implemented a range of authentic inquiry-based activities into the secondary teacher's classroom. Graduate and undergraduate fellows have spent the autumn and winter quarters in secondary and high school classrooms to develop an appreciation of learning environment of each school and to develop a rapport with students and teachers. During this period the fellows also interacted with the secondary school teachers and the university faculty to explore an activity that could be implemented in the teacher's class during the mid-part of the spring quarter. They were instructed to plan a simple, but meaningful, activity, and learn the process of activity development, lesson plan development, implementation and observation, evaluation, assessment, reporting, and finally dissemination. The objective was to train them to understand the critical issues that need to be considered in each of these areas. Based on the input and guidance from the secondary school teachers and the university faculty the fellows developed the activities reported in this section. The fellows also interacted with the evaluation team to develop the evaluation plan and assessment strategy for their activity in advance, and with the technology team to explore how multi-media tools and computer-based methods (e.g., data acquisition and display if probes are used) can be effectively integrated in their activity and presentations. One Education faculty member in the project team and the Project Area Coordinator instructed them on the use of LiveText software to create lesson plan templates, insert appropriate national and state standards, and create evaluation rubrics for their evaluation strategy. They once again reviewed with the fellows on how evaluation results can be used to conduct assessment and how to draw conclusions from the results. They also reviewed what constitutes authentic learning. So, the first year was devoted to training the fellows on acquiring these skills, and this goal was accomplished.

Classroom activities were designed to fit the teachers and students' needs based on curriculum requirements, course content, students' abilities and interests, and available resources. Activities were incorporated into lessons, demonstrations, laboratory exercises, individual and group projects, and field experiences and range from several small group projects to several two to three daylong projects. A key ingredient of all these activities is that they involve "open-ended" problems seeking an optimum solution. Critical thinking, higher-order learning, active learning,

“hands-on” experience, collaborative learning, teamwork, writing, and presentation skills are integrated in these activities. Based on the need of the school and curriculum requirements, a range of activities were designed and implemented by the fellows. These activities range from evaluation of alternative energy sources for a community, to estimate photosynthesis potential from satellite images, to survival of fish communities in an environmentally stressed eco system. They range from designing futuristic rocket propelled cars that run the fastest to space rockets that reach to greater heights. Some of these projects not only integrated science and math, but also History and English classes. A description of these projects is provided below, with photographs for some presented as Figures 1 to 7.

Clearly, these activities cover a wide spectrum of topics; yet, they have provided valuable experience on how to integrate these projects over a range of time frames into different courses, with different numbers of students, levels of involvement, and grade-levels. As well, several other skills were identified for the secondary students to effectively participate, e.g., ability to work in teams, focuses on tasks, and take an active role in their learning. The teachers and the Principal Investigators of Project STEP are currently developing several interconnected activities that will be used for the next year. Depending upon each team’s interests, different classes and/or schools may collaborate on similar activities with the goal of peer interaction. In the remaining part of this section example of eighth activities developed and implemented by the fellows during the first year are presented.

Viva Las Vegas Energy Project

The Las Vegas Energy Project required freshman physical science students at Hughes Center, an urban Cincinnati school, and at Amelia High School, a middle class suburban school, to work in groups of three or four to evaluate an electrical generation technology (wind, hydroelectric, nuclear, and solar) for use in the Las Vegas area. Las Vegas was a natural site for such a case study because it currently draws power from a wide variety of technologies and because Las Vegas is almost mythical in its electrical consumption and recent population growth. The students researched different aspects of their group’s assigned technology in order to write a report and develop a presentation with a visual aid. The students were assessed on their research, the report, the presentation, and the visual aid.

The purpose of the project was for the student’s to demonstrate their ability to evaluate the effects of a technology on community, to summarize the processes by which we obtain electrical energy, and to present their researched evaluations in the form of a formal written report and as a poster presentation. The goal of the students was to convince the Las Vegas City Council (the fellows and the teachers) to choose to build the type of power plant assigned to their group.

Although there were slight differences between the ways in which this project was implemented at the two schools, the final forms were essentially the same. On the first day, the fellows presented a detailed PowerPoint presentation introducing the students to the unique conditions of Las Vegas and to the assignment as a whole. Over the course of the presentation, each student was presented with an overview of the project, a calendar of due dates, and a copy of each rubric that would be used to assess their results. Also that day, the students were placed into groups where their first task was to compose a responsibility list detailing the role each group member would play over the course of the project. Students then signed their responsibility lists, which were kept on hand by the fellows throughout the project to settle the inevitable disputes. At both schools, the next two days were devoted to online and book research. At Hughes, students worked at a computer lab, as no computers are present in the classroom, while at Amelia, they worked in the classroom. After the two days of research, Hughes students were given approximately one week in class to write their research papers, prepare their visual aid, and outline and practice their presentations. Graded progress checks, in the form of rough drafts, were due every other day in order to keep the students focused. At Amelia, this work was expected to be completed outside of the class. As a result, some, but very little, in-class time was devoted to developing the project. Final drafts of the research paper were due from every group on the first day of presentations. Presentations lasted two days at both schools. After the presentations were completed, students responded to a survey-type evaluation of their work, the work of their peers, the project as a whole, their technology use, and their academic habits.

Assessment of the written report, the presentation, and of the visual aid was conducted via the detailed rubrics designed before the implementation of the project. Immediately after each presentation, the fellows and teacher would mark directly on copies of the presentation and visual aid rubrics and tally the group’s scores. The Fellows similarly assessed the written reports at a later time. A view of this rubric is presented in Figure 7.

Students at both schools responded favorably to the Las Vegas Energy Project. At Hughes Center, the final grades roughly followed a normal distribution, with a mean of 84%. Scores were lower at Amelia, due mainly to a lack of response on the written report. Qualitatively, the most significant differences in the implementation of the activity at the two schools were in the research skills of the students and in their motivation. Students at Hughes were much less efficient or successful at using the World Wide Web to retrieve relevant information on their power plant than were those at Amelia. In their surveys, Hughes students claimed to use computers for school work far less than those at Amelia, a fact probably related to both classroom and at-home computer availability. This discrepancy in research ability manifested itself in the presentations. Hughes

students were more professional and poised during their presentations, but lacked much of the data presented by their Amelia counterparts. On the other hand the Amelia students had good presentation material, but lacked coordination when different members of the group presented it. In terms of motivation, Hughes students appeared more interested by the project. On their surveys, Hughes students reported both higher desire to get good grades and a higher parental involvement with schoolwork than did those at Amelia. Students at both schools claimed to have learned more than they had initially expected over the course of the project. One thing that was enlightening was to observe the extent to which the students became aware about the ethical and economical issues when justifying their selection for the energy source, and how alert the other students were to question their justifications.

The fellows were also educated over the course of the project. The main classroom teacher at both schools was absent for at least one day during the course of the activity, leaving the fellows in the presence of a substitute teacher, but essentially in charge of the classroom. Previous experience in classroom management, however, helped the fellows keep the classes under control and working steadily. The fellows also planned to a larger extent than had been required in earlier lessons. The fellows mapped out, in detail, the course of each of the eleven days of the project at Hughes. Almost every aspect of the project, from the micro-lessons to the classroom procedures, was planned in advance. Of course, at both schools, sudden changes were made to keep pace and to smooth points of misunderstanding. By the end of the Las Vegas Energy Project, fellows and teachers at both schools were very satisfied that the project had met its objectives.

Rocket Cars

This activity was implemented in a ninth grade math class in Western Hills University High School. The purpose of the rocket car activity was to experiment with ways of increasing the distance and speed of a rocket car, analyze data graphically, and communicate results. The students in this math class were largely inner city students and about 2/3 of the class was minority. This activity provided students with the opportunity to plan and design a car with limited materials. Each car had to perform, and students had to discuss any problems they encountered during construction and make changes from the original plans. Students were divided into groups of two. Since the students were of an age group that they were or will soon be driving on their own, this project seemed to appeal to their interest from the very beginning.

The rocket car project was modified from a project found at a NASA Website. Students used foam meat trays for the basic body and a balloon with a straw for the propellant. The main modification was that the original project used fixed axles and rotating wheels (e.g., a disk attached to the car with a pin); for this project, the students

were give solid axles with attached wheels. The wheels and axle were the stick and plastic disks taken from "push up" type ice cream treats. At first, the students had trouble dealing with the solid axle. Some attempted to tape the axle to the body and then found it would not rotate. Eventually, one group discovered that taping a soda straw to the bottom of the car and placing the axle through the straw allowed the axle to rotate. The other groups then copied this idea. The students also found that size, weight, wheel alignment and placement of the balloon (in some positions it drags) affect the outcomes.

Each pair of students collected five trial runs with their car and recorded the data on time and distance in a table. They completed all calculations using $d = rt$, where d = distance, r = speed, and t = time. Students used the data to create a scatter plot and linear regression to find the equation of the line of best fit. Upon further analysis, students could connect the speed with the slope of the line. Students used the data to evaluate their cars critically, including description regarding strengths and weaknesses of the project and their car's performance and any necessary improvements.

The fellow reported that the students responded well to the project and showed enthusiasm. Several problems were encountered. Due to absenteeism and/or lack of interest, some of the students could not perform the required mathematical analysis, even through this topic had been previously presented. Some were not able to explain why their car performed as it did. Finally, some students did not participate, leaving the other group member to do the work. The fellow suggested the following improvements: provide clearer instructions, assess the needed math skills and provide review as required, provide a clear explanation of grading/assessment criteria and ask for partner assessment to prevent one partner from abdicating responsibility.

Sound Activity

A three-day activity was designed to introduce the fundamental concepts of sound through instruction and hands on activities at Liberty Junior School. The targeted group of students was composed of eighth grade physical science class, which had a random assignment of students. The random selection process produces classes that contain a wide range of abilities among the students. The majority of the students were from a middle class suburban environment, and had no previous exposure to the fundamental scientific concepts of sound. The primary goal of this activity was to clearly convey the fundamentals of sound through demonstrations and experiments, while relating these concepts to real world and engineering applications.

The breakdown of the three-day activity included a fixed 45-minute allotted time each day for instruction, along with a similar time for experimentation at eight stations arranged along the periphery of the classroom. The stations provided an opportunity for hands-on activities where the students could interact and record their observations. The

first day provided an introduction to how sound is produced and in what form it travels. This led to the wave nature of sound and some of its characteristics such as amplitude, frequency and wavelength. Students were educated on what levels of sounds can be perceived by humans, animals, and mammals. They were also told about sound levels produced by equipment they see everyday. They were shown what equipment is used measure sound, and how the signatures (amplitude and frequency plots) recorded look like for sounds produced by different sources. This enabled the students to clearly understand the scientific terms used to describe sound motion, which often is seen to be lacking in university students even. Demonstrations involving tuning forks, oscilloscope and a function generator were provided to assist in explaining the material, as well as to expose the students to modern laboratory test equipment. Other forms of technology including a decibel meter and laptop computers were available for experimenting at some of the eight stations. The instruction and demonstrations were quickly followed by the eight experiments that the students had to do on their own, in groups of three, using the instruction sheet supplied to them. They had to record their findings on a worksheet.

The second day of instruction reviewed some of the fundamentals learned during the first day, then introduced new concepts including the speed of sound and the Doppler Effect. New topics were introduced through demonstrations and were also related to engineering applications. Students were given nearly one half of the class period to explore at the stations and to further complete their worksheet.

The third day completed the visitation of stations and the students were presented with a surprise quiz. In addition to the quiz, the students completed an evaluation of the activity in order to document appropriate feedback and to determine ways to improve the activity.

Practically all of the students found the interactive stations extremely helpful in understanding the material. An equal number of students found the use of new technology and equipment to be enjoyable. Surprisingly from the evaluation results, the students weren't too enthusiastic about demonstrations performed by the fellow. Many students seemed to enjoy hands-on activities and working in groups as opposed to worksheets and individual assignments at their desks. The students appeared to be engaged from the first day of the activity when they walked into the classroom and noticed the new equipment setup throughout the classroom. The anticipation of hands-on experience with new technology and an opportunity to experiment was observed through the enthusiastic behavior of the students. The combination of lecture and stations each day provided a good balance of instruction and experimentation.

The fellow reported that there were several things that can be taken from this activity that will be considered when designing future activities. A few things worked well in this activity, including the opportunity for the students to play with various sound producing and recording devices to learn

about sound. The students worked well in groups and were attentive during periods of instruction. One limiting factor in this activity was that the students had no prior knowledge of the subject matter. If the students were previously exposed to the fundamental concepts, a more challenging and in depth activity would have been developed.

Magnetic Fields

Activities were designed to teach high school seniors about magnetism at Hughes Center. The students in the physics class where this activity was performed were largely inner city, minority students. Given the time period allocated (4.5 hours in 3 sessions) and equipment available, six activities were implemented. The first two activities were more educational in content to hone down the basic knowledge the students need to acquire before being exposed to advanced topics. The fellow designed the third activity on magnetic field strength. The fourth activity was a hands-on activity in which the students constructed a device using magnetism principles learned. The fifth and sixth activities dealt with real world applications highlighting the wide use of the technology in the real world and need for more. Hopefully the students left this activity with a desire to learn more about it.

The first activity was to verify the right-hand rule used to determine the direction of magnetic field generated by a straight wire carrying electric current. The students put a current into a wire and then found the magnetic field direction with a compass. They verified the right hand rule through a simple hands-on experiment and physical observation. It was thought that the understanding of this principle was very important before moving on to more advanced topics.

The second demonstrated that an electromagnet could be made stronger by increasing current, voltage or the number of turns of the wire around the core. Students explored all possibilities and observed the impact of each. This made them think critically what factors will have a significant impact on performance.

The third activity required students to verify the formula $F = BIL$ using previously learned knowledge in mechanics, where F is magnetic force, B is magnetic induction, I is electric current, and L is the length of conductor. Students set a copper pipe on a support to make a trapeze. The copper pipe was connected to a circuit and placed within strong magnetic field. When electric current flows in the circuit, the pipe will be subjected to a magnetic force and the trapeze will swing from its initial equilibrium position to a new one. The weight of the pipe was given to the students. Then, they were required to measure the movement of the pipe and calculate the swing angle of the trapeze. From mechanics (taught previously) the students could calculate the magnetic force F exerted on the pipe based on the pipe weight and angle of movement. The students had to use the concept of free-body-diagrams, which undergraduate engineering students learn in more detail in the mechanics

courses they take in college. The students then measured the magnetic induction, B , using a sensor, record the electric current, I , from the power supply display, and measure the length, L , which is the length of the pipe within effective range of the magnet. Then, they calculated the magnetic force applied to the pipe using the formula $F = BIL$. The students compared the two values and needed to identify reasons that make the two values of F different. This lesson pointed out the problems inherent to most experiment work, i.e., the inherent error in the measuring equipment. For example, the students used a meter to measure the induction of the system, but the meter was very sensitive and the students had a problem getting an accurate reading. They also had a problem accurately measuring the distance the pipe moved.

The fourth activity was to construct a simple electric motor using copper wire. The students were divided into groups of 3-4 students, and each group constructed their own motor and operated it. Some groups, who were more careful in winding the copper wire tight and in constructing supports that offered minimum resistance, were able to get their motors to work sooner. This challenged the other students to work harder, talk to their peers what they could do to improve – peer learning was in full action in the class. Ultimately all groups got their motors to work, and the students were excited to see “science in action.” The fellow then gave examples where such motors are used in equipment the students’ see everyday, and other more special applications, such as in the medical area. A big discussion pursued amongst the group members at the end of the day – which gets to take the motor home to show!

The fifth and sixth activities were guided demonstrations of electromagnetic induction and how a transformer works using primary and secondary solenoids.

The fellow reported that the students were engaged throughout the activity. The sequencing of the hands-on activities with the lectures and demonstrations provided an atmosphere in which the students were active participants. The activities also provided problem-solving opportunities, and exposure to issues related to real scientific research. The use of technology and multi-media tools made it easy to convey the principles taught. Good three-dimensional drawings were presented to illustrate the concepts (e.g., the right-hand rule), which were physically then verified through experiments. The real-world examples presented were carefully chosen and were the ones that the students could relate to, and that enhanced their desire to know more. The fellow pointed out that if he were to implement the activity again, he would prepare more detailed instructions on the use of the equipment for the experiments, and finer details of care needed to construct the electro-magnetic motors.

Water Rockets

This activity was conducted in a ninth grade physics and earth communities class at Western Hills University High

School, and involved making and launching rockets made from two liter soda bottles. Pressurized water is the propellant. This activity has been used in many schools and the fellow was able to provide the students with Websites on the project. The project was very timely since the Challenger disaster was still fresh in the minds of the students.

The fellow first showed a movie called *October Sky*, which is a fictional account of students in a poor coal-mining town attempting to win a rocket competition to earn college scholarships. As part of a History class, the students were also asked to read material on how the Cold War influenced and advanced rocket design.

The students were then shown a demonstration of a plain, two-liter soda bottle launched as a rocket. The bottle simply tumbled out of control. With this as the starting point, the student attempt to build a rocket that performed better.

The rockets were launched using a commercially available bottle rocket launcher that provided the same propulsion to all the rockets. Students were graded on how high the rockets flew. The students measured the height in two ways. First, they recorded the descent time of each rocket. Applying the descent time to a physics formula, $y = 1/2 gt^2$ (y = height, g = gravitational constant, and t = time), gives an estimate of the maximum height. Second, they recorded the angle to apogee from the rocket to the ground where they were standing. This angle was recorded using an instrument made from simple classroom materials; a ruler taped to a protractor with a weighted string attached to the center of the protractor. The students aim the ruler at the highest point of flight and the weighted string (acting as a plumb bob) provides the angle from the horizontal. Using the distance along the ground from the launcher, the angle, and a little trigonometry, it is possible to derive a rough idea of the height of the rocket. The students compared the two measurements and discussed accuracy and possible sources of error. Each group was provided with the performance results of all the groups, which included the one that did the best. They were required to use this information to explain why their design performed the way it did, and how could it be improved to make it the best. This forced them to revisit their work and think about their design critically – a strategy often adopted when developing new technology.

The fellow reported that the students were very excited as rockets went off successfully. They all wanted to shoot their own rockets multiple times. The behavior was excellent and attentive, and there was no trouble getting people involved in taking measurements. Boys and girls alike were enthralled by the activity. Students that had previously never picked their heads off of a desk all year were all of a sudden asking what was next in the lesson plan.

The students learned about the Cold War and how it influenced the science of rocketry. They learned how to analyze the design of a water rocket and what factors affected the flight. Students were introduced to the concepts

of the propulsion system. They learned how to better take measurements, how to use the measurements to derive usable quantities or characteristics and about graphing a trajectory. The students were able to describe factors that could possibly affect rocket flight other than design characteristics (i.e., weather conditions, etc.) They also learned from the movie that hard work and study could help one achieve goals. As part of their English class they had to write about their whole experience.

The fellow also reported that he learned what factors affect water rocket flight. For instance, large wings flap in the wind and produce marred flight due to turning sideways or slowing down due to wind resistance. If he had to do the project over again, he would give them some advance training on what works and what doesn't so that the students would be more successful in their design, further helping motivate them to achieve and put more into school and get more out of it.

Eco Systems

In Shroder Paedia School two major projects were performed over the course of a week in an eighth grade science class. One activity was a fish lab experiment, and the other activity was a moon research project.

In the fish lab experiment, the lab was initially a one-week lab where the experiment was designed so that due to man-induced alterations in the eco-system the fish were supposed to get sick over the course of the week and then were brought back to their normal living conditions. This was to demonstrate to the kids that when fish are taken out of their normal living environment then fish could get sick. Similarly, when humans are taken out of their normal living environmental conditions, or are exposed to abnormal environmental conditions then humans can get sick. This relationship showed to the students that chemical and environmental engineers play a vital role in the society to assure that safe and healthy living conditions are not violated. Unfortunately, when the fish were taken from pH levels of 7.4 down to 6.8, the fish brought the levels of pH back up through their excrement. This was done a second time to see again. Since this occurred it was explained to the children that sometimes humans are similarly able to adjust. However, since it was observed that the fish became agitated when the pH levels were dropped, there were three beakers set up. One that was much lower than normal, one beaker with normal pH, and the third beaker with pH levels much higher. This then showed to the kids immediately that the fish were having problems with the environment change.

In the second activity, the students were given the scenario that the earth was being over populated and humans need to move to the moon or a space station. Initially they were advised to explain what they think is important in our eco system and then how to create our eco system on a space station, keeping in mind things like gravity, food, water, oxygen, and communication. They were also then told to understand the relationship of their subject to a certain

engineering profession. For example, a group was given the subject of gravity and they were told to figure out how gravity would be simulated in a space station and how that would be related to what a civil and mechanical engineer does. Each group was given a different aspect to consider, conduct the research using material available on the Web and available books, and make a short presentation.

The students' reactions to these activities were that they were very inquisitive. They asked lots of questions and were able to understand the relationships from their lectures. For example, when the fish experiment was demonstrated to them, they were immediately able to understand that some sort of pH indicator was being used to measure the pH levels. The students were also able to explain how this related to jobs performed by chemical and environmental engineers to make the living environment safe and comfortable. For the moon research project the students initially tried to figure out for themselves how their desired environment could be created in a space station. Then if they were unable to understand they asked many questions. When the students did the preliminary exercise of determining what is important in the eco system they would like to live in, many were immediately able to identify water, food, and gravity needs. Then, when the students had the initial list proposed, they started adding to the list other desirable things dealing with safety, such as bomb shelters. This could have been influenced by the recent events of war in the news. Overall the students understood a lot from the activities that were performed.

Photosynthesis Through Satellite "Eyes"

This activity related satellite technology to science was implemented at Glen Este High School. A hands-on activity was developed to demonstrate how using satellite imagery one could assess photosynthesis. It was designed for 10-12 graders as part of an environmental science class, and was a two-period activity. Basically the activity consisted of an introduction, activity presentation, the activity itself, and assessment of learning and comprehension. This whole knowledge was completely new for the students.

In the introduction a warm up question was posed: Why are plants green in spring/summer and brown in autumn? The students were asked to write an answer. Then they were presented with the explanation how chlorophyll pigments break the sunlight absorbing blue and red lights and reflecting green. Furthermore a comparison between human being's vision and what a satellite sensor sees and presents was presented. The students were then introduced to the activity they will be conducting. They were told how satellite sensors are designed in such a fashion that they let us "see" how blue, green and red lights can be used to differentiate what is being observed, and that near infrared light is also reflected by plants, something that our vision cannot capture. A PowerPoint presentation was made to further explain this concept to the students. One of this visual aid is presented in Figure 5. After it, the students

analyzed satellite images of the school neighborhood. These images were distributed in digital files. One half of the class worked with green, red and near infrared images taken in wintertime and the other half worked with images taken in summer time. The activity guided the student to see the differences detected by satellites, something we cannot see, and to write down their conclusions with explanations. Through this activity the students also learned about Geographic Information System (GIS) software, and in particular ArcView® Spatial Analyst. This was a new experience for them. Essentially Spatial Analyst extension in the ArcView® software, which is a public domain software, allows students to work with digital numbers and colors together. Unfortunately this extension was not available in the school, which caused a confusing to the students in the beginning. Redirecting the students to observe shades instead of numbers solved this problem. The whole exercise taught them a good lesson that often scientists get limited by the resources available to them, but then they have to explore alternative rationale procedures to solve the problem, if possible.

The PowerPoint presentation captured the students' attention. It successfully motivated the students to learn the basic concepts. The students asked questions about the satellite technology as they went through the activity. They became curious about space travel, and enquired about how they could become an astronaut. A simple rubric was designed to assess the student learning and retention. The students were asked to view images, analyze them, and write their conclusions. They were also asked to write a fictional essay on: "You are in living in 2200. In 2100 human beings' vision had improved. Now humans could see ultraviolet light as violet rays and near infrared energy as golden color. Describe how you would see Glean Este back yard."

Acid and Bases

This activity was implemented in a tenth grade chemistry class at Shroder Paideia School. In this activity, students compared and distinguished the properties of acids and bases and applied this knowledge to a real-world problem. The students were divided into groups, but each student had to maintain their own activity record book. First the students measured and compared the pH value of various household products using the CBL and the pH probe. Household products used included: lemon juice, white vinegar, soap, baking soda, soft drinks, ammonia, and milk. Later on, students measured the pH level of the water in a fish tank during three days and observed how goldfish react to the different pH levels. They recorded their behavior.

Most students participated in the lab activity very eagerly. There were many questions asked on the using and functioning of the probe, and how to interpret the results displayed on the graphical CBL (computer) screen. The students had to wear goggles to participate. After measuring the pH level of household products, each group went to the fish tank and took some water to measure its pH. In the fish

tank, there were four big goldfishes. After one day only the fish tank became dirty because it was too small to hold four goldfishes. Also, someone had given them too much food.

Most students' responses to the activity were very positive. For the assessment, there were four survey questions. Each question had four choices: strongly agree, agree, disagree, and strongly disagree. About 93% students felt that this activity was very helpful to understand what acids and bases are and how knowledge about them is essential to understand about the contents of the commonly used household products. About 60% students agreed that this activity increased their interest in science. However, 35% of students disagreed. Number three question was: "The activity was well organized." About 72% agreed, 23% strongly agreed, and 5% disagreed. Overall, 95% students felt that the activity was well organized. For the last question, 95% students agreed that the activity was important to improve understanding in the classroom. As shown by this survey, most students preferred an activity over lecture on a topic. To measure the improvement in students' academic achievement, students took the pre-test and post-test. Even after the lecture and watching videotapes, students' pre-test scores were very low. The average pre-test score was only about 5 out of a total of 16. The average post-test score was about 10. Female students score varied from 5 to 11. They did better than male students, whose score varied from about 4 to 9. Thus, after completing the activities the post-test substantially improved.

The fellow reported the requirement imposed by the teacher that the students had to bring their own goggles to wear when doing the experiments posed a problem. Often some students forgot to bring their goggles, and they were a big source of distraction to the others. The fellow recommended that a better solution should be explored before imposing such restrictions. The fellow also noted that if he were to repeat the activity he would not only use a larger tank but three tanks and vary the pH value in each manually so that the students can see the impact it has on fish behavior.

OUTREACH ACTIVITIES PLANNED IN THE PROJECT

The faculty and fellows working on the grant are planning an Open House for teachers, community members, university and secondary school administration, and Oversight Committee members in order to share our results with the community at large. The Oversight Committee consists of four community leaders, and will provide subjective input and guidance to Project STEP. The Open House will take place on Friday June 20, 2003 in order to disseminate activities to teachers in the schools, wrap up the school year, review the goals of the grant, and transition smoothly into the next phase of the grant. This was not originally planned in the grant proposal for the first year, but

the Project Committee thought that this would help make the university and secondary school administrators more aware of the project developments, and also provide a forum for the project Oversight Committee to meet and provide input.

The Open House will be an opportunity for the fellows to showcase their work for teachers, faculty, and administration. In addition to dissemination of activities, the fellows will also have an opportunity to work with the teachers to develop goals for their work over the summer months. It is planned to add two additional secondary schools next year; participating teachers from these schools will be invited.

In addition to this specific outreach the goals of the grant include outreach to the local, state, and national community. Project STEP has two primary goals. The first goal is to produce scientists, engineers, and secondary science and mathematics educators who are experienced in developing and implementing authentic educational practices into current secondary science and mathematics curricula. These university students have brought their technical background and expertise into the classroom guided by the current experienced teachers so that the students can be effectively engaged and can relate science, technology, engineering, and mathematics (STEM) knowledge they learn to the world they live in. They have been and will continue to be exemplary in enhancing and reinforcing basic scientific and mathematical concepts by integrating inquiry-based, open-ended problems pertinent to the student's community. Even if every fellow does not pursue a teaching career, they are forming partnerships between education, business, and community. They may inspire their businesses to directly and/or financially support local schools, they may bring their expertise through part-time teaching, or may use their skills in designing friendlier technology to better suit societal needs.

The second goal is to design, develop, and implement hands-on activities and technology-driven inquiry-based projects, which relate to the students' community issues, as vehicles to authentically teach STEM skills. The idea is to enable middle and high school students to directly experience the relevancy of their education to everyday life, society and the world in a way that requires them to use higher-order thinking skills. In this context, we view higher-order thinking as 'when a person must interpret, analyze, or manipulate information, because a question to be answered or a problem to be solved cannot be resolved through the routine application of previously learned knowledge' (Onosko and Newmann, 1994). Authentic learning, when used in tandem with various technologies, offers opportunities for high student involvement, motivation for students to do their best work, encouragement for students to use high-order thinking skills, and opportunities for students to engage in conversations in which they persuade, summarize, argue, and compromise (Grégoire, Bracewell and Laferrière, 1996). Through these two goals, the activities of the grant reach students, teachers, and university faculty

locally and nationally through presentation and publications described in that section of the report.

Two graduate fellows and their research advisor working on the project also collaborated to organize and implement a 'Bridge Building Competition' among local area high schools. The competition was designed to give students the opportunity to learn how engineers use math, science and technology to design real structures. The competition was held for the first time on February 14, 2003. The students built their bridges at their high schools and brought them to the university for the day, and are tested for strength and stiffness. The bridges were constructed of wood and glue. Individual pieces of wood could not exceed ¼" wide x ¼" deep. There were no limits on the length of individual wood pieces. Sound engineering practices such as truss construction, gussets and metered joints were encouraged. The bridge mass was limited to 0.68 Kg. Eighty-eight teams and 188 students participated. The day included the competition, a tour of the campus, and engineering activities for the students. Awards were given to best strength, best stiffness, and best overall performance. For more information about this activity, visit the website, <http://www.eng.uc.edu/resources/collegenews/bridge/>.

CONCLUDING REMARKS - FINDINGS DURING THE FIRST YEAR

Through the work of the grant the 2002-2003 year, we have successfully engaged fellows in meaningful, productive, and innovative educational instruction and activities and they have become excited about and motivated to teach STEM skills in K-12 math and science classrooms. As a result of this instruction, the fellows realize and understand that the facets of education, research, and professional activities overlap and that this overlap can help them to be more successful in future careers. The educational instruction of the fellows has included university faculty and secondary teachers providing instruction, guidance, and mentoring to fellows in the practice of instructional approaches and best teaching practices. The fellows have had ample opportunities to observe and participate in middle and high school math and science classrooms. Because of the training the fellows received this year, they were able to design, develop, and implement secondary level authentic, inquiry based learning activities based on their technical expertise and knowledge. Over the next year of the grant the fellows will be trained in the development and implementation of more comprehensive projects and activities centered around two focal areas, mechanics and physical science (including chemistry, physics, earth science, and environmental science), and with mathematics threading between the two. This will provide an opportunity to show how math and science are inter-related – which was identified as a need by the teachers who participated this year. It should be noted that the areas of mechanics and physical science would still cover the focus thrusts in Civil Engineering and

Environmental Engineering and Science, as mentioned in the previous section on Research and Education Activities Planned for the Project. The fellows will incorporate computer modules using electronic multimedia and web-based tools for the activities they develop. It is planned to add two additional secondary schools to the project next year.

In addition to the successes with the fellows, we have also had success with the secondary teachers, students, and schools. Through the implementation of the activities and the presence of the fellows in the classrooms, we have recognized an increased interest in math and science. Although no data was collected directly from the students through the evaluation team this year, many fellows collected data and are working on analyzing the data to help them develop activities for next year. The fellows did conduct pre- and post- evaluations for the activities they implemented this year to access the impact these activities had on student learning and comprehension. They also suggested modifications and extensions for future implementations. Fellows developed an electronic portfolio documenting their experiences. These will be put on the project Website during the summer of 2003. The portfolio incorporates the goals and objectives of the activity they implemented, standards addressed, description of the activity, implementation details, evaluation rubric used, evaluation results, and personal reflections. Many fellows commented that the students were more involved in the activities developed as a result of this grant than in other activities throughout the school year. The secondary math and science teachers were instrumental in the training of the fellows; the fellows spent two quarters (over 120 hours) with the teachers in their classrooms observing, learning, and participating. Through this interaction with the teachers the fellows were able to design, develop, and implement activities that were directly related to the school, state, and national curricula for science and math.

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TABLE I:
DEMOGRAPHICS OF THE SCHOOLS PARTICIPATING INSTEP

Secondary School and Location	Grade Levels	Number of students	% African-American	% Hispanic	% Asian	% White, Other	% Free/Reduced Cost Lunch
Amelia High School ^f	9-12	1338	1	0.9	0.9	97.2	11
Amelia Middle School [*]	7-8	1144	1	0.9	0.9	97.2	13
Glen Este School [*]	7-12	2214	1	0.9	0.9	97.2	13
Hughes Center High School ^{**}	9-12	1800	85	0.4	0.5	14.1	40
Liberty Junior School ^f	7-8	800	4	0.8	2	93.2	7.5
Shroder Paideia School ^{**}	7-12	621	85	0	0	15	39.5
Western Hills High School ^{**}	9-12	1800	58	0.3	0.2	41.5	50

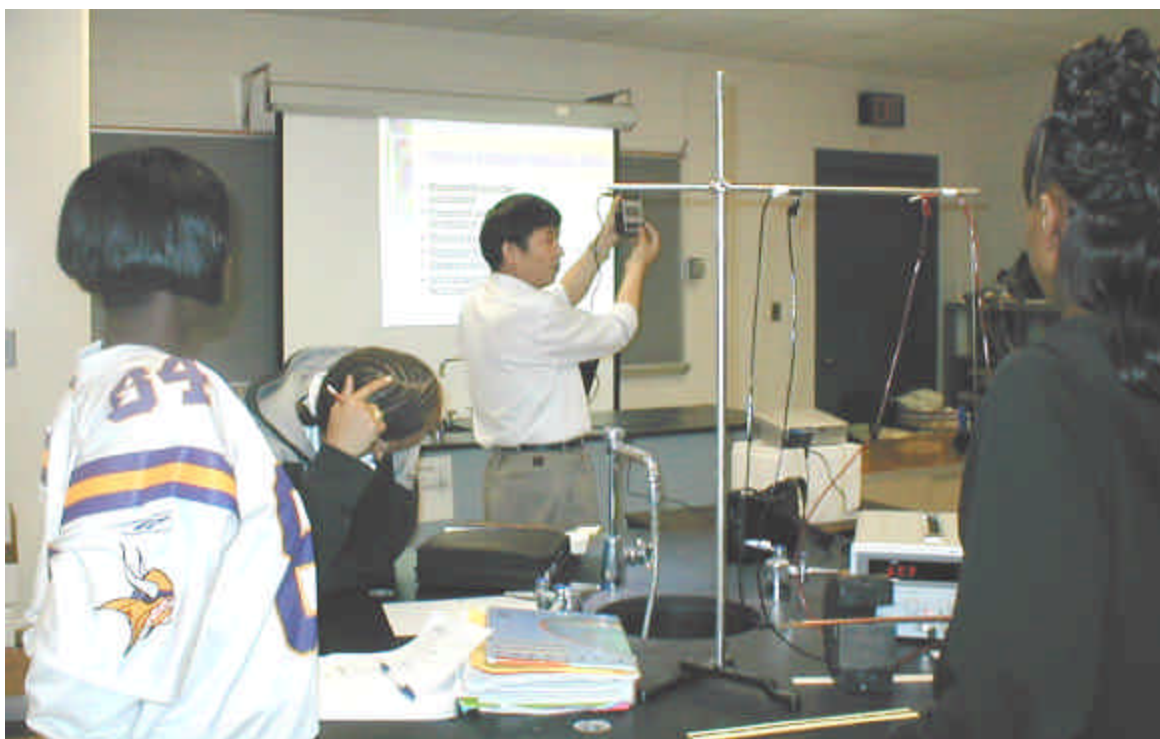


FIGURE 1
FELLOW DEMONSTRATES THE MEASUREMENT OF MAGNETIC FIELD EXPERIMENT TO STUDENT AT HUGHES CENTER



FIGURE 2
TWO HUGHES CENTER STUDENTS MEASURE THE MAGNETIC FIELD



FIGURE 3
A ROCKET CAR MADE AT WESTERN HILLS UNIVERSITY HIGH SCHOOL



FIGURE 4
A GROUP OF WESTERN HILLS UNIVERSITY HIGH SCHOOL STUDENTS WITH BOTTLE ROCKETS

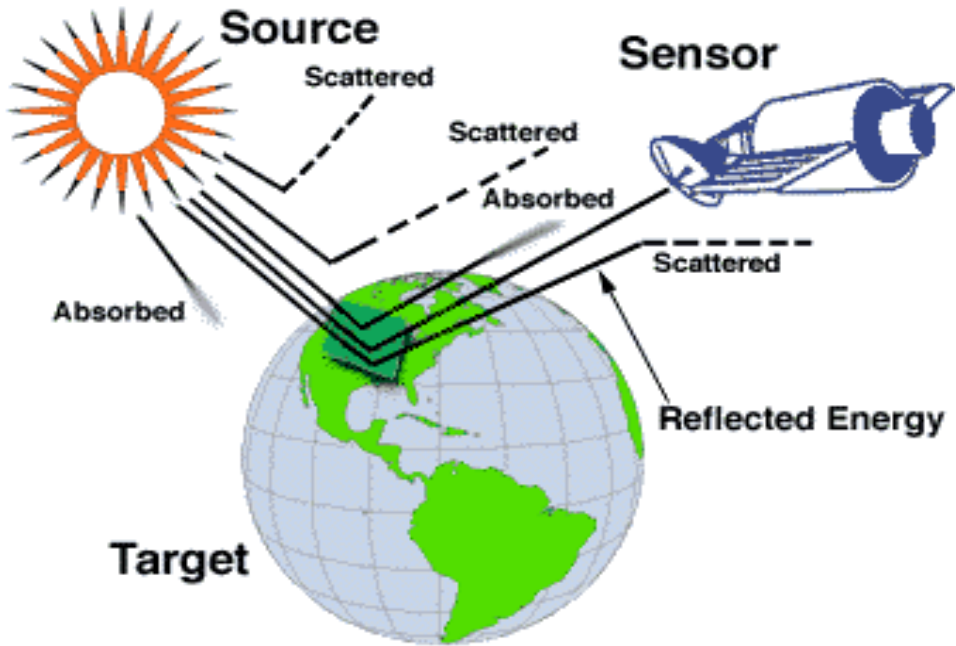


FIGURE 5
VISUAL AID USED TO EXPLAIN TO STUDENTS HOW DO IMAGING SATELLITES WORK



FIGURE 6
VIVA LAS VEGAS STUDENT GROUP MAKING A PRESENTATION

SOLAR 1st Home

Grading Rubrics

Power plant research paper (Group Portion)

Component	0 points	2 points	3 points	4 points	5 points	Point Value	
Introduction	None present	Very little information/not clear.	Some information, but not clear	Information adequate, but unclear	Informative and clear.	5 points	3.5
Flow	Paragraphs are unconnected and seem out of order.	Most paragraphs are in order but are not connected	All paragraphs are in order, some transition between them	Paragraphs in order, transitions are adequate	Great flow-paragraphs make sense, and fit together seamlessly	5 points	4.2
Conclusion	None present	Very little information/not clear.	Some information, but not clear	Information adequate, but unclear	Informative and clear.	5 points	3.5
Rebuttal	None present	Very little information/not clear.	Some information, but not clear	Information adequate, but unclear	Informative and clear.	5 points	5
Presentation/editing	No paper turned in	No evidence of proofreading/illigible	Poor spelling, informal language, poor grammar. Most paragraphs legible	Some minor spelling/grammar mistakes. Generally legible.	Spelling and grammar are great. Paper is very clean and easy to read (best if typed).	5 points	3.5
Daily Progress-Grade	No progress ever	XXXXX	XXXXX	XXXXX	Mostly on task/ rough draft ready on Wed. 5-7-03	5 points	5
TOTAL						30 points	

22.5
30

FIGURE 7
AN EXAMPLE OF A GRADED RESEARCH REPORT RUBRIC FOR THE LAS VEGAS ENERGY PROJECT

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