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Jiang Zhe

University of Akron Main Campus, jzhe@uakron.edu

Dennis Doverspike

Julie Zhao

Paul C. Lam

University of Akron Main Campus

Craig C. Menzemer

University of Akron, main campus

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High School Bridge Program: A Multidisciplinary STEM Research Program

Jiang Zhe, Dennis Doverspike, Julie Zhao, Paul Lam and Craig Menzemer

The University of Akron

Scientific and technological innovations have become increasingly important in the 21st century as our economy is built on a foundation of science and engineering (NSF, 2007). One concern for the U.S. in the 21st century is the competitiveness of the workforce in science, technology, engineering and math (STEM) fields. According to a NSF report (NSF, 2007) “the nation is failing to meet the STEM education needs of U.S. students, with serious implications for our scientific and engineering workforce in the 21st century” (pg. v). A recent report to Congress indicates that “there is growing concern that the United States is not preparing a sufficient number of students, teachers, and practitioners in the areas of science, technology, engineering, and mathematics (STEM)” (Kuenzi, 2008). The United States currently ranks 20th among all nations in the proportion of 24-year-olds who earn degrees in natural science or engineering.” If this situation continues, the U.S. may lose its leadership in innovation and discovery that has greatly benefited our economy.

The solution is to produce a sufficient pool of qualified graduates in STEM areas to face the benefits and challenges of both globalization and a knowledge-based economy (NSF, 2007). This is also essential for the continued economic success of the nation and its national security (NSF, 2007).

However, the supply problem in STEM areas has long been a challenge for American universities and colleges, and it is likely to worsen in the near future. According to the report to Congress (Kuenzi, 2008), the overall proportion of STEM degrees awarded in the U.S. has historically remained at about 17% of all postsecondary degrees awarded. Also, postsecondary degrees in math and physical science have steadily decreased in recent decades as a proportion of all STEM degrees awarded. Meanwhile, many other nations have seen rapid growth in the number of STEM degrees awarded (Kuenzi, 2008).

An early research experience is one of the most effective avenues for attracting and retaining talented students in science and engi-

neering careers, including careers in teaching and education research. This paper describes a 10-week long summer program designed to build interest in STEM careers among high school students. Four research projects were developed based on the principles of involved activity. The goal of the program was to expose high school students to challenging engineering problems and to increase their self-confidence in academic areas.

Increasing Career Interest

In order to reduce labor shortages in the STEM occupations and to increase diversity in terms of backgrounds, it is necessary to engage students before they enter post-secondary education. For that reason, a program was developed that targeted high school students, with the intent of developing a high school to college bridge program.

According to a comprehensive literature review of 66 reports involving science education for students (Mastropieri & Scruggs, 1992), knowledge and learning are facilitated through providing activities-oriented science curricula. Thus, the use of hands-on research activities would lead to better learning for high school students in their teens. In addition to better learning, such activities should lead to increased self-confidence and career motivation.

Design of the Program

Based on a review of the pertinent literature (Access STEM, 2007; Gosselin & Macklem-Hurst, 2002; Mastropieri & Scruggs, 1992; Norman, 1997), it appeared that the best approach to building interest and self-confidence was one that relied upon inclusive, inquiry-based science, emphasized problem-based learning, and incorporated visual demonstration. Group work and active learning-based teaching have been proposed as effective practices for use with students and teachers (Access STEM, 2007; Gosselin, & Macklem-Hurst, 2002; Norman, 1997).

In addition, given the diversity of the students

Abstract

A Science, Technology, Engineering and Math (STEM) summer Bridge Program was developed for high school students. The program was designed to encourage students to consider choosing an engineering major in college and to explore STEM as a future career. This was accomplished through a 10-week program involving multidisciplinary research activities. The participants in the program included 33 high school students. Among participants in position to make a choice in terms of attending college, 100% chose to continue on in college, and 86% chose to major in a STEM area. Comments received in focus groups suggested that the participants viewed the program positively and that it did impact their career plans.

in the program, principles from the universal design of educational programs (Access STEM, 2007; Dolan & Hall, 2001; Grumbine & Alden, 2006) were incorporated. The universal design of educational programs involves developing curricula that are usable by all people, to the greatest extent possible, without the need for adaptation or specialized design (Burgstahler, 2006a, 2006b; Dolan & Hall, 2001). Important principles in creating course content include: 1) providing multiple media for presentation of material and delivering material clearly and in multiple ways; 2) motivation of all students; 3) designing training to accommodate diverse learning styles; 4) the use of large, tactile aides; 5) providing for cognitive and memory support including emphasis of major points and outlines; 6) making training practical, relevant, and hands-on; 6) facilitation of interaction through group work; and 7) allowing for peer interaction and feedback (Burgstahler, 2006a, 2006b).

Based on these principles, four hands-on research projects were identified for the development of workshops. The projects were: 1) Testing and Characterization of Modern Steel Components; 2) Development of a Smart Balloon, including sensors and information technologies (Zhe, Zhao, & Lam, 2006); 3) Hybrid Car Powered by Water and Sunlight; and 4) Strain Gage Sensors for Mechanical Infrastructure Health Monitoring. The selected projects cover 4 major engineering fields: civil engineering, mechanical engineering, electrical engineering and chemical engineering. Projects 2, 3 and 4 are multidisciplinary.

Description of the Projects

1. Testing And Characterization of Modern Steel Components

The first project was designed to familiarize students with physical testing, mechanical properties, strain and displacement sensors for monitoring structural activity and health, data collection and data reduction techniques for a range of modern steel products. Three sub-projects included: A) material characterization; B) bearing strength of modern steels; and C) the testing of mechanically fastened connection elements.

a) **Material characterization** included both tensile testing and impact toughness characterization of plate and bar products. Students were asked to conduct mechanical tests to determine yield, ultimate, and elongation characteristics of various steels. In addition, impact toughness testing was

Steel Type	Classification
<i>HS(250)</i>	<i>High Strength</i>
<i>HS(400)</i>	<i>High Strength</i>
<i>HS(550)</i>	<i>High Strength</i>
<i>DP(550)</i>	<i>Dual Phase</i>
<i>DP(700)</i>	<i>Dual Phase</i>
<i>DP(980)</i>	<i>Dual Phase</i>

Table 1: List of Steels for Tensile and Charpy Testing

conducted on the same materials over a series of temperatures in an attempt to examine the upper, lower, and transition regions of impact toughness. Table 1 lists potential steels that were employed as part of the project.

The steels used in sub-project A covered a range of strength characteristics and provided some interesting toughness comparisons. Charpy tests were conducted at room temperature, 500°F, -104°F and -320°F.

At least four Charpy replicates per temperature were conducted and average impact toughness vs. temperature curves were developed. A minimum of 10 to 12 tensile tests per material were conducted. This activity provided students with an opportunity to statistically evaluate the material properties and develop an appreciation for the establishment of design allowables.

b) **Bearing Strength** of steels is an important property for the design of bolted, riveted, and pinned connections. At least three of the steels identified for mechanical testing were used to examine bearing strength. Testing variables included steel strength, material thickness, edge distance and fastener (hole) diameter. Samples were simple sheet type coupons, measuring 4 in. wide and 12 in. long, and were fabricated with a fastener hole at one end, located one, one and a half, two or three bolt diameters from the bottom edge. Each sample was loaded to a specified target and then unloaded. Careful measurements of the hole before and after loading were made and compared. Students were asked to make plots of bearing stress versus hole elongation, and to assess the bearing strength-hole deformation relationship.

c) **Connection Elements** are used in a number of structures to connect different members together or as a means to splice different components. These elements often employ mechanical connections or welds as a means to join the different components together. Over the years, methods used to proportion and design connection elements have changed rather dramatically. Joints are critical to the adequate performance of many engineered systems as applied forces must flow through items like connection plates. The recent collapse of the I35W bridge in Minnesota is an example highlighting the critical nature of connection design and performance.

Steels employed during material characterization and bearing strength evaluations were intended to be used to size several connection plates for testing. The students began to use the tensile and bearing strength properties obtained during the first two portions to proportion the connection elements. While the connection element specimen design was not completed when the program ended, the intention was to examine the role of fastener gage and joint length on the capacity of the connection plate. Gage spacing affects the tensile capacity of the connection element whereas the length influences the shear strength.

2. Development of A Smart Balloon

This project was designed to expose participants to the central concepts and hands-on experiences of state-of-the-art space surveillance, sensor technologies, and information and communication technology (ICT). The project was centered on designing and testing an intelligent balloon by high school students tutored by undergraduate engineering and graduate students who had developed a smart balloon (Zhe, Zhao, & Lam, 2006).

A balloon is non-polluting and vibration-free. It is a highly reliable platform for many applications including scientific research and military use. The balloon provides quick response times, long duration flights, unlimited configurations, nearly unlimited launch sites, and fully recoverable payloads. It is an excellent vehicle for space, atmospheric environmental qualification, and meteorological measurements.

In the 10-week project, the students designed, assembled, and launched a tethered intelligent balloon assisted by two undergraduate students, one in mechanical engineering and the other in electrical engineering. The balloon



Figure 1: Tensile testing of steel alloys

was equipped with a wired temperature sensor, a wired pressure sensor, an imaging sensor, a data collection and storage device, a wireless temperature sensor, a receiver and a transmitter for wireless communication. The intelligent balloon was launched up to 500 feet. Temperature, pressure, and imaging information were collected from onboard devices. Temperature and pressure data were compared to the NASA model (NASA Glenn Research Center, 2008), as a check on agreement.

3. Hybrid Car Powered by Water and Sunlight

The third project was designed to provide an introduction to the basic concept of utilizing solar energy and hydrogen fuel cell technology. Since the depletion of natural oil deposits is inevitable, new energy sources must be found to provide power for civilization. Utilization of solar energy and hydrogen energy is an extremely critical research area world-wide.

The students built and tested a model car that was powered by water and sunlight. The car consists of: 1) a solar panel that delivers solar energy; 2) an electrolyzer that decomposes water to hydrogen and oxygen; 3) a polymer electrolyte membrane (PEM) fuel cell to generate power for the hybrid car; and 4) an electric motor to drive the car.

The hybrid vehicle worked in the following way: The electrolyzer used electricity from the solar panel to decompose water into hydrogen and oxygen gases, which were stored in the attached graduated cylinders. When power to the car was required, the fuel cell was connected

to the onboard electric motor. The fuel cell then converted the hydrogen and oxygen gases back into water, releasing electricity, which powered the electric motor and drove the car forward.

The students were guided to explore the following engineering and science concepts:

- How electrolysis produced gas components from water using solar energy.
- How the orientation of the solar panel affected electrical energy output.
- How a hydrogen fuel produced an electric current when used in a fuel cell.
- The relation between the amount hydrogen consumed vs. the amount of work done by the electric motor.
- Future implications of changing to a hydrogen-powered economy.

4. Strain Gage Sensor for Mechanical Infrastructure Health Monitoring

The fourth project was designed to familiarize the students with a structural health monitoring system consisting of strain gage sensors, the Wheatstone bridge circuit, and data acquisition. A structural health monitoring system using sensors can improve safety margins and reduce the maintenance cost of advanced machines including vehicles, watercraft, aircraft, etc; it can eliminate manual inspection and provide the capability for prognostic determination of remaining lifetime and maintenance scheduling.

In the project, first the student attached two strain sensors to the surface of a cantilever beam using appropriate adhesives (Figure 2a). A strain gage sensor, a small section of very fine wire, experiences electrical resistance change when it is subjected to mechanical strains. When a force was applied to the beam by adding a weight at the tip, it bent down in proportion to the force. As the beam bent downward, the top of the beam stretched in tension while the strain gage on the bottom of the beam was compressed. As a result, the top and bottom strain gages sensed an increase and decrease in resistance. The students were asked to measure the resistance changes individually using a multimeter. When the changes were small, they may not be measured accurately with the multimeter. Next the students were guided to build a half Wheatstone bridge in the breadboard that amplified the measured resistance change and measured the strain on a cantilever beam as a load was applied at the end of the beam (Figure 2b). The next step involved having students measure the resistance change of a cantilever

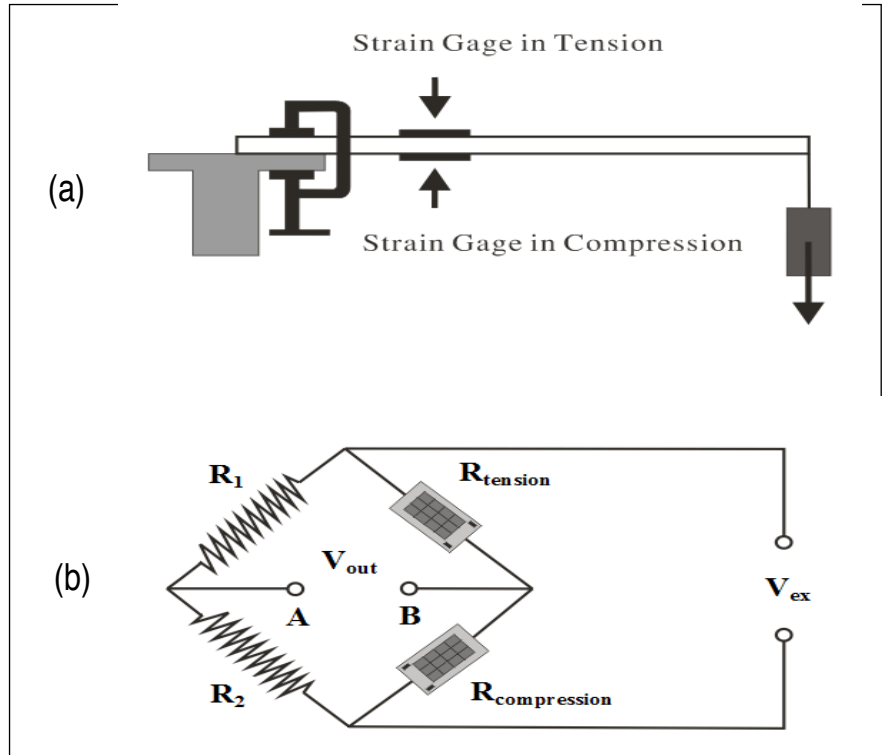


Fig.2 (a) Illustration of strain gage installation, (b) Wheatstone bridge setup for mechanical strain measurement

beam with cracks/damages. They were asked to measure the difference in resistance/strain under the same applied force. They learned that from this difference it is possible to judge the existence and position of the damage.

The specific activities included:

- Exploring working principles of strain gage sensors.
- Building a Wheatstone bridge circuit to detect the resistance change and convert the changes into mechanical strain.
- Calculating the Gage factor using the LabVIEW® program.
- Using strain gage sensors to measure strain of deformed beams made of different materials, including steel, aluminum, wood, etc.
- Conducting research on the use of sensors for health monitoring

Program Management

The workshops were designed so that high school students were involved in a research project in conjunction with a faculty member and graduate student mentor. The students were divided into three major groups according to their interests: one group (13 students) working on material characterization, bearing strength of modern steels and the testing of mechanically fastened connection elements; a

second group (10 students) working on smart balloon; and a third group (10 students) worked on the solar fuel car and the structural health monitoring sensory system. Thus, each group did one major project except for the third group, which was involved in two major projects over the 10 weeks.

Students from different high schools worked together in various hands-on activities. The program gave the participants opportunity for direct observation and participation in on-going research activities. The projects also fostered an atmosphere that promoted the development of a mentoring relationship between the student, faculty members, and current engineering graduate students. Such relationships are often critical to student success.

The workshops were held over 10 weeks of the summer. The students were asked to meet with graduate tutors and faculty members in the corresponding research lab at least two days (16 hours) per week. They were welcomed to spend more time in the lab. After one week of training, the faculty assigned the students research tasks. The students were required to participate in a weekly group meeting with the graduate tutor to report the progress and discuss technical issues. Once a week the graduate tutors reported to the corresponding faculty regarding student progress.

At the end of the 10 weeks, the students were asked to make presentations to the faculty members and graduate tutors. Their parents were invited to the presentations.

Participants

The participants in this program were high school students who were in grades ten to twelve in high school. To recruit the students, advertisements were sent to local high schools. All of the participants had expressed a previous interest in STEM, which led them to apply for the Bridge Program. Thirty-three (33) applications were received before the deadline and all of the applicants were accepted.

The students represented 10 local high schools, all of which were geographically close to The University of Akron. Of the 33 high school

participants, 15 were female and 18 were male. In terms of ethnicity, 25 were White, 6 African American, 1 Asian American and 1 Hispanic. The demographics of the students in the program are summarized in Table 2.

Evaluation of College Admission Data

One question that could be asked is, *was the program successful in encouraging students to attend college?* Up to the spring semester of 2009, 21 of the participants were in a position where they had to make a college decision; the remaining 12 were still at a point in high school where they had not applied or had not yet made a college decision (See Table 3). Of the 21 participants who were in position to make a college decision, all 21 (or 100%) had decided to attend and had been admitted to college. Of those, 17 were attending, or would be attending, the University of Akron. Four were attending other colleges. Thus, the program was very successful in terms of encouraging students to attend college and attracting students to the University of Akron.

Evaluation of Choice of Major

The second question that could be asked is, *was the program successful in terms of attracting students to STEM as a major?* There were 21 participants who had chosen to attend college and all of these students had chosen a major (See Table 3). Of the 21 students, 18 (86%) had chosen a STEM major and 3 (14%) had chosen a non-STEM major. Thus, the program was successful in achieving awareness of college STEM majors and encouraging students to maintain their commitment to STEM.

Qualitative Analysis of Focus Groups

Focus groups were conducted by faculty members and the program director. At the beginning of the summer research, each faculty mentor held a focus group to gather information

	Class Levels			Gender		Ethnicity			
# of students	Sophomore	Junior	Senior	Female	Male	White	African Amer.	Asian	Hispanic
33	2	16	15	15	18	25	6	1	1

Table 2: Demographics for Students Participating in the Bridge Program.

on students' expectation, interests and skills, so the task of the research activity could be adjusted and the groups could be assigned to match students' background. A group meeting was conducted every week with the graduate tutor to report the process and allow for in-depth discussion of a topic, thus to encourage student researchers to discover new insights. After the final presentation, another focus group was run by the faculty mentors and program director to collection evaluations and suggestions on the program improvement. The program director oversaw the program through observations and interviews.

The focus groups were used to identify positive and negative themes. The main positive was the opportunity to work on a research project with a faculty member. Associated with this opportunity was the: 1) flexibility of the program; 2) opportunity to acquire new knowledge and skills; and 3) the interaction in a team environment. A few quotes from the focus groups are given below:

"The bridge program allows me to work with college students and familiarizes me with the college environment. The design project gives me hands-on experience and I decided to choose the Mechanical Engineering as my major at the University of Akron."

"The Bridge program was my first true independent research. This meant that a lot of the work was done on my own, although I was able to turn to my advisor for help. The Bridge program really taught me lessons on how to manage my time because with approaching deadlines and meetings, I had to prearrange my time in a proper matter. Also, I was able to enhance myself with programming skills that most college students really do not learn well until their sophomore year."

"The summer bridge program was a very great experience. I enjoyed working with the other students that were also interested in the mechanical engineering field. I involved with two projects: the first one was the solar cell car, and the other one dealt with circuits and amounts of strain on certain materials. The fuel cell car was interesting because it may be an option for a source of energy for cars in the near future. The other experiment was very difficult at first, but I liked it more because it was a little bit more complicated and challenging. Everyone I worked with was very nice and helpful. I also really liked the fact that the hours were very flex-

	<i>College Admission</i>		<i>Major Choice</i>	
<i># of students</i>	<i>UA</i>	<i>Others</i>	<i>STEM</i>	<i>Others</i>
<i>21</i>	<i>17</i>	<i>4</i>	<i>18</i>	<i>3</i>

Table 3: College Admission Status and Major Choice.

ible and fit right into my schedule. This was a very great opportunity for me and for any student that is interested in an engineering field."

There were two main negatives cited. One was the lack of flexibility. At first this might seem to contradict with listing flexibility as a positive, but here the participants were referring to the limited number of possible research areas. In particular, there was a desire to have more projects in additional science areas such as biology, chemistry, and medicine.

The second negative that was mentioned was that they would like to work on "more challenging" projects. The students had intentionally been asked to repeat some research activities that had already been worked out in faculty's lab, considering the limited scientific background and limit time frame. Again, paradoxically, another small group of students also commented that projects, for instance, sensors for structure health monitoring, were "too challenging" to finish in a couple of weeks. Although these comments were contradictory, they reflected a common core that there was a failure to meet the expectations of the participant groups in terms of project difficulty and complexity.

Summary

In conclusion, the Bridge Program led to a positive increase in knowledge and attitudes toward STEM careers for high school student participants. Among those former participants in position to make a choice in terms of attending college, 100% had chosen to continue on in college. In addition, 86% had chosen to major in a STEM area. From this perspective, the program was judged to be a success. One theme that emerged during the focus groups with the students was that the program had enhanced their confidence in STEM majors and independent research and that exposing them to problem-solving research projects had motivated them to consider a career in STEM.

A major limitation was the lack of quantifiable data. One of our future plans is to intro-

duce a survey process, so that numeric results can be tracked over time. Regarding changes to the program, the biggest problem identified by the students was the lack of flexibility in terms of choice of research projects. This primarily related to their interest in exploring a wider variety of areas including biology and medicine. This is a change that will be considered in the future.

Also in the future, the program will be organized in a tier-mentoring and real research-oriented structure. More advanced and less advanced students will be grouped together; the group will work with a graduate tutor/researcher to conduct real independent research in the faculty mentor's lab. One of the more advanced high school students will be assigned as the leader of the team for the sub-task, controlling the progress, tutoring the less advanced students, and reporting to the graduate tutor and/or the faculty. The graduate student tutor will only provide assistance and guidance. The students will be asked to come at least 4 hours every business day and to attend a weekly group meeting to discuss the progress and failures they met with the graduate tutor and the faculty, and to determine the research direction for the next week. This organization will place the participants in a more realistic research and team environment.

Overall, the students were very positive in their evaluation of the program and expressed appreciation for the opportunity. In terms of career goals and management, the students indicated that the program did help them to make a choice of college and major. In addition, many students said the structure of the bridge program, including group meetings, presentations, campus tours and social activities, opened their mind to the realities of college life.

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Jiang Zhe, Ph.D., is an associate professor of Mechanical Engineering at the University of Akron. His research interests include MEMS, sensors and actuators, microfluidics devices, smart materials and structures. He is currently working on intelligent sensors for bioparticle detection, and micro scale transducers for micromanipulation and structure health monitoring. He has authored or co-authored 45 technical papers and is the authors of two US patents.



Dennis Doverspike, Ph.D., ABPP, is a Full Professor of Psychology at the University of Akron, a Fellow of the Institute for Life-Span Development and Gerontology, and Director of the Center for Organizational Research. He serves on the Board of IPMAAC and is Chair of the Professional and Scientific Affairs Committee. Dr. Doverspike holds a Diplomate in Industrial/Organizational Psychology from the American Board of Professional Psychology and is a licensed psychologist in the State of Ohio. He has over twenty years of experience working with consulting firms and with public and private organizations. Dr. Doverspike is the author of 2 books and over 100 refereed journal publications. He also provides consulting services in the areas of Industrial Psychology and Human Resource Management.



Julie Zhao, Ph.D., is Director of Increasing Diversity in Engineering Academics Program and Visiting Assistant Professor at the Department of Electrical and Computer Engineering, The University of Akron. Her research interests include wireless communications and engineering education.



Paul C. Lam is Professor and Associate Dean of Undergraduate Studies, Diversity Programs and Co-op Education Director in engineering at The University of Akron. Research interests include structural dynamics, fatigue and fracture evaluation of material behavior, pre-engineering and minority engineering retention issues. He received his BS degree in 1969 at Purdue University, MS degree in 1970 at University of Illinois, and PhD at The University of Akron in 1978. In 1996 Dr. Lam was elected as an ASME Fellow and also the recipient of numerous outstanding teacher awards.



Craig Menzemer, Ph.D., is an associate professor of Civil Engineering at The University of Akron. His research interests include fatigue and fracture behavior of structures, behavior and design of connections, structural simulation and engineering education. Dr. Menzemer is the co-author of a book and numerous papers in refereed journals and conference proceedings. In addition, he has nearly 14 years of industrial experience.

