Relationships between Self-efficacy and STEM Knowledge Exam Scores in a Short-term Intervention Program: A Pilot Study

Mr. Tony McClary, New Mexico State University, College of Engineering

Tony McClary is a Master’s candidate in Curriculum and Instruction at New Mexico State University. Tony received his Bachelor’s degree in Performance Psychology from New Mexico State University in 2014. Tony is currently working with the College of Engineering on developing an assessment for middle school and high school students who attend short-term intervention programs in an effort to understand if and how these camps help students.

Dr. Patricia A. Sullivan, New Mexico State University

Patricia A. Sullivan serves as Associate Dean for Outreach and Public Service and is Director of the Engineering New Mexico Resource Network in the College of Engineering at New Mexico State University. She received her PhD in industrial engineering and has over 32 years’ experience directing statewide engineering outreach services that include technical engineering business assistance, professional development, and educational outreach programs. She is co-PI for a National Science Foundation (NSF) INCLUDES grant focused on collective impact strategies involving STEM outreach, Co-PI for a Broadening Participation grant to increase minority engineering students through engagement in innovation and entrepreneurship, and a Co-PI for an i6 Challenge grant through the U.S. Economic Development Administration (EDA) to foster regional economic development through innovation and new business start-ups. She is institutional integrator for the Partnership for the Advancement of Engineering Education (PACE) at NMSU. She is also co-lead for a NSF funded Pathways to Innovation cohort at NMSU with a focus on integrating innovation and entrepreneurship into the engineering curriculum through a blending of industry and educational experiences. Patricia serves as a commissioner for the Western Interstate Commission for Higher Education (WICHE), is a member of the executive committee for the NM Consortia for Energy Workforce Development, a member of the board of directors for BEST Robotics Inc., and a member of the board of directors for Enchantment Land Certified Development Company (ELCDC – a program that certifies SBA 504 loans that foster economic development.) She has extensive experience in economic development particularly efforts that build on collaborative partnerships with business and industry, government agencies, and other stakeholders to enhance employment opportunities for engineering students.

Dr. Steven J. Stochaj, New Mexico State University

Prof. Luis Antonio Vazquez Ph.D., New Mexico State University

Dr. Luis A. Vázquez is the Associate Vice President for Research Integrity and a Regents Professor. Dr. Vázquez earned his Doctorate degree in Counseling Psychology from the University of Iowa in 1990.

Dr. Vázquez’s greatest interest is the "empowering" focus of research on the ethnically/racially diverse populations in education. He has published in the areas of acculturation, and educational development, along with developing multicultural training videos used across the country in counseling and psychology programs. Dr. Vázquez has been an invited speaker at numerous National Conventions to address the issues of Academic Success and health disparities in underserved populations. He has been a visiting professor at the Universidad Autónoma de Mexico in Mexico City, Mexico. He currently serves on the Council of Representatives for the Psychological Study of Culture, Ethnicity and Race, Division 45 of the American Psychological Association. Among the awards Dr. Vázquez has received is the Presidential Citation from the American Psychological Association for Visionary Leadership in Psychology, USDA Faculty Fellow in Washington D.C., as well as several "Excellence in Teaching Awards." He is also a consultant through KMA (Kochman, Mavrelis & Associates-kmadiversity .com) to higher education institutions in the areas of personnel development and policies of diversity.

Dr. Karen Trujillo, New Mexico State University

Dr. Karen Trujillo has been an educator for over 20 years. She started as a teacher, became an administrator and has been a research faculty member at NMSU for six years. She has been a PI and Co-PI of
multiple grants focused on STEM Education. She is the director of The Alliance for the Advancement of Teaching and Learning and recently started the STEM Outreach Alliance Research Lab (SOAR) to study the impact of STEM Outreach efforts at NMSU.

John Kulpa
Self-Efficacy and STEM Knowledge Exam Scores in a Short-Term High School Intervention Program: A Pilot Study

Introduction

STEM outreach programs are at the forefront of efforts to increase the number and diversity of students entering college in pursuit of STEM degrees. Across the U.S., STEM outreach programs are undergoing a paradigm shift from systems that measure the success of programs by counting the number of student participants to those that focus on engineering the next generation of STEM students. In the new paradigm a student’s growth in the areas of technical skills, soft skills and engineering mindset are assessed and the data is used to modify the outreach curriculum to increase the number and quality of students pursuing STEM degrees.

NMSU is at the forefront of this national trend to develop assessment tools for STEM outreach programs and to modify programmatic content to meet the learning styles of today’s youth. As a work-in-progress, this study was conducted to determine whether a similar relationship exists between technical content knowledge and self-efficacy when observed in a short-term STEM summer intervention program among high school students. It is important to understand how these two variables are related. This paper introduces the methodology used to support and enhance future STEM outreach programs curricula, discusses program outcomes, and provides enhancements to assessment tools for future STEM programs. It is hoped that the outcomes of this research effort will lead to a blueprint for broadening participation in STEM through enhanced summer intervention programs.

Background

Self-efficacy has long been studied as a predictor of people’s mental and physical performance. Bandura described self-efficacy as the perception of one’s own ability to complete a given task. Self-efficacy has been linked to an individual’s likelihood of pursuing and persevering in a program or course of action. In an academic context, self-efficacy has been shown to reliably predict academic performance and the likelihood of pursuing technical and scientific careers. Recently, self-efficacy was shown to be a strong predictor of academic performance among underrepresented individuals in the STEM fields including females, Hispanic students, African-American students, Native American students, and students from low socio-economic backgrounds.

Freeman et al. has identified active learning as an important predictor of student achievement. Active learning may be described as “having students engage in some activity that forces them to reflect upon ideas and how they are using those ideas” and “keeping students mentally, and often physically, active in their learning through activities that involve them in gathering information, thinking, and problem solving.”

The majority of studies describing links between self-efficacy and performance are focused on long-term interventions and how self-efficacy can be affected over the course of months or years. The purpose of this study was to examine whether or not a two-week, residential STEM intervention program for high school students—NM PREP Academy—had a measurable effect
on student confidence (a subcomponent of self-efficacy) and content knowledge. We also aimed to gain a greater understanding of how similar short-term intervention programs could be used to increase interest, participation, and persistence in STEM-related careers, as well as to understand which specific portions of the program were most closely related to the students’ gains in either knowledge or confidence. Our research questions were as follows:

1. Did the confidence and/or content knowledge of the students change as a result of engagement in the pre-engineering program?
2. Was there a relation between changes in student confidence and knowledge?
3. Was there a relation between active learning and gains in student knowledge?
4. Did the pre-engineering program impact a student’s inclination to participate in additional STEM activities and/or pursue engineering as a career?

Method

Program

The NM PREP Academy is a two-week residential, immersive engineering education program that engages students in a content-based engineering curriculum from 8:00 am to 5:00 pm. Directly following, they are given the opportunity to explore activities designed to improve teamwork and leadership skills while exposing the students to various experiences faced by first-year college engineering students, including lectures and design challenges. Students designed and built bridges, explored electrical networks, created posters and presented these posters in an environment similar to a professional conference. The instructors for the lectures and design challenges included NMSU College of Engineering professors and engineering graduate students. The exploratory activities included a “Mission to Mars” where students served in various positions onboard a vessel en route to Mars in a “Mission Control” simulation. A graduate student in curriculum and instruction served as the program’s Activities Coordinator and was responsible for the exploratory activities that took place after the classroom activity hours. The students spent roughly one-third of each day attending lectures and two-thirds of each day doing hands-on and exploratory activities. A sample daily schedule is provided in Table 1.

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00 a.m. – 8:00 a.m.</td>
<td>Breakfast</td>
</tr>
<tr>
<td>8:00 a.m. – 10:00 a.m.</td>
<td>Civil Engineering/ Bridges Lecture</td>
</tr>
<tr>
<td>10:00 a.m. – 12:00 p.m.</td>
<td>Bridge Design (paper)</td>
</tr>
<tr>
<td>12:00 p.m. – 1:00 p.m.</td>
<td>Lunch</td>
</tr>
<tr>
<td>1:00 p.m. – 3:00 p.m.</td>
<td>Balsa Wood Bridge Building</td>
</tr>
<tr>
<td>3:00 p.m. – 5:00 p.m.</td>
<td>Bridge Strength Testing</td>
</tr>
<tr>
<td>5:00 p.m. – 6:00 p.m.</td>
<td>Dinner</td>
</tr>
<tr>
<td>6:00 p.m. – 8:00 p.m.</td>
<td>Exploratory Activity (LCPS Challenger Center for Space Science Education)</td>
</tr>
<tr>
<td>8:00 p.m. – 9:00 p.m.</td>
<td>Reflective/Down Time</td>
</tr>
<tr>
<td>9:00 p.m.</td>
<td>Lights out/ Bed Time</td>
</tr>
</tbody>
</table>
Curriculum

The NM PREP high school curriculum was designed by the Engineering New Mexico Resource Network (ENGR-NM) staff utilizing feedback provided by the participating engineering faculty members. The ENGR-NM leadership team met with members of the engineering faculty to identify activities and to discuss the science behind them as a means of introducing students to the various engineering disciplines offered by the college. Each department provided an activity they thought would best engage students, while providing them with some of the technical skills needed to be successful future engineering students. A dry-run of the activities was conducted by two undergraduate engineering students who were employed specifically to test the proposed activities. The dry-run was intended to provide additional insight on how students received and reacted to the activities, ensure that the materials identified were indeed sufficient to complete the task at hand, ensure the activity’s curriculum was easily understood and could be completed within the given time constraints, and most importantly, ensure the respective activities were appropriate for high school students.

Participants

The participants for this study were taken from the NM PREP program in compliance with NMSU IRB policies and procedures, and consisted of students in grades 9 to 11 (between 13 and 17 years of age). Of the 41 students who participated in the program, 31 were male students and 10 were female students. Although diverse, the population was mostly represented by Caucasian and Hispanic students. In addition, the high school locations were primarily urban and spread out across 13 school districts. Finally, most students came from public high schools. The 41 participants were selected from over 300 applicants based on the following criteria: their most recent math and science grades, their most recent PARCC (Partnership for Assessment of Readiness for College and Careers) test scores, and their response to a written essay question.

Consent and Data Gathering Procedures

The participants and their parents were asked to sign a consent form upon check-in to the academy outlining the purpose of the study. On the first evening of the academy, all of the participants were divided into two classrooms. One group took the paper-based content exam and the other group took the computer-based self-efficacy survey. After all the participants in each group finished their respective tasks, the students switched rooms and completed the other task. On the last full day of the academy, the participants returned to the same classrooms and completed the two tasks again. The order in which the students took the tests was randomized and the participants were given the same amount of time to complete the tasks as they were given on the first day.

Content exam. The content exam was composed of 31 questions designed by the ENGR-NM staff to test students’ knowledge of the material covered in the program. The exam measured engineering vocabulary, problem solving, and technical skills. The test had 91 possible points (67 points in vocabulary, 19 in technical skills, and 5 in problem solving). Each question had a value of one point and the total score was the number of correctly answered questions. The content exam was reviewed by members of the engineering faculty to ensure that the questions aligned with the knowledge expected of first year engineering students.
**Survey.** The self-efficacy survey was created by the ENGR-NM staff in collaboration with research faculty from the College of Education STEM Outreach Alliance Research (SOAR) lab using Survey Monkey. The survey included several sections. Students were asked to rate their confidence level in various STEM subjects, situations required to be a successful engineer, and particular activities they would encounter during the program. They were asked to compare themselves to people who perform engineering tasks, and rank their knowledge of and interest in various engineering careers. Students were also asked to rate specific pre-engineering program experiences, and finally, in open-ended questions, students were asked about the “best” part of the program and what improvements could be made. Due to the low number of participants, validation of the survey tool is ongoing.

**Analyses**

Of the 41 students who participated, 32 completed the content knowledge exam before and after the program. The exam provided scores in three content knowledge categories: (1) vocabulary, (2) problem solving, and (3) technical skill. Of the students in the program, 34 completed the self-efficacy survey before and after the program. This survey provided confidence scores in two categories: (1) academic and (2) technical. The scores in these categories were a function of students’ answers on 11 (academic) and 12 (technical) individual survey items. Of the 41 students who participated in the program, 27 students completed the content knowledge exam and the self-efficacy survey both before and after the program. The quantitative analyses reported below was based on data obtained from those 27 students and the qualitative analyses was based on the responses of the 34 who completed the survey both before and after the program.

We were especially interested in determining the efficacy of the academy in terms of two variables—(content) knowledge and confidence. Difference scores (post-test minus pre-test), representing knowledge gain were calculated for each student within each of the knowledge subcategories (vocabulary, problem solving, and technical skill). A measure of overall knowledge gain was derived by summing across these categories for each student. A similar procedure was followed for confidence: Difference scores representing confidence gain were first calculated for each survey item for each student. Within each confidence subcategory (academic and technical), confidence gain was represented for each student by summing these difference scores across the items belonging to that category. Overall knowledge gain for each student was then obtained by summing across the academic and technical confidence gain measures.

Answers to the open-ended questions (e.g., best part of the program and suggested improvements) were analyzed systematically. First, two researchers independently reviewed the students’ responses, looking for patterns and related ideas. Categories corresponding to these related ideas were then agreed upon by the researchers. The researchers then independently assigned each individual response to a category. In cases where the researchers assigned a response to different categories, they discussed the discrepancy and came to a consensus about placement. Finally, frequencies of individual responses belonging to each category were recorded.
Results

Research Question 1: Did the confidence and/or content knowledge of the students change during the NM PREP program?

Students’ overall knowledge clearly increased (Figure 1), as evidenced by a significantly positive knowledge gain ($M = 17.4$, $t(26) = 10.0$, $p < .001$). In contrast (Figure 2), there was no corresponding increase in overall confidence ($M = 1.4$, $t(26) = 0.9$, $p = .189$, n.s.).

![Content Knowledge](Figure 1. The change in scores on engineering content knowledge exams given before and after the program to the 27 high school students included in these analyses. Error bars represent one standard error of the mean above and below their respective sample means.)

![Confidence](Figure 2. The non-significant change in confidence scores on self-efficacy surveys given before and after the program to the 27 high school students included in these analyses. Error bars represent one standard error of the mean above and below their respective sample means.)
These findings are consistent with the participants’ perceptions of their learning in the academy. Students were asked in an open-ended format whether they had learned new math and/or science concepts. Seventy-nine percent of the students claimed to have learned at least one new math or science concept.

Research Question 2: Was there a relation between changes in student confidence and knowledge?

In addition to exploring the influence of the program on knowledge and confidence separately, we were interested in a possible relation between knowledge and confidence. While no significant correlation was found between these variables in the pre-test scores ($r = 0.11, t(25) = 0.5, p = .299$, n.s.), they were significantly related at post-test ($r = 0.46, t(25) = 2.6, p = .008$). That is, after the program but not before, knowledge and confidence tended to vary together; students with more/less engineering knowledge tended to be more/less confident about their abilities. The post-test relation suggests an association between knowledge gain and post-test confidence. In support of this association, a significant correlation was found between overall knowledge gain and overall post-test confidence ($r = 0.40, t(25) = 2.2, p = .020$). Those students with high/low knowledge gain tended to have higher/lower confidence after the program.

Research Question 3: Was there a relation between active learning and gains in student knowledge?

Active learning was one of the response categories that emerged from the open-ended question about the best part of the pre-engineering program. Particular responses classified as active learning included individual and group projects, hands-on activities and experiments, and field trips.

Of the 34 students included in the analyses, 11 (38%) mentioned the active learning component as the best part of the program, while 23% of the students wished to see more hands-on learning, and 15% wished to see less lecture during the academy. To more thoroughly explore the potential benefit of implementing curricula that emphasize active learning, we looked at the students’ change in knowledge as a function of whether they fell into the group that mentioned active learning. The change in knowledge ($M = 16.5$) for those that mentioned active learning was not significantly different from the change in knowledge ($M = 18.1$) for those that did not mention active learning ($t(23.5) = -0.43, p = .671$, n.s.).

Research Question 4: Did the NM PREP program impact a students’ inclination to participate in additional STEM activities and/or pursue engineering as a career?

An important goal of the NM PREP program is to reveal to students their academic engineering capacities along with inspiring them to follow a path leading to a degree and a career in an engineering-related field. When asked about their future career interests in an open-ended format on the post-survey, 79% of the students saw themselves pursuing a degree in engineering. The students were also asked to rate the following statement on a 5-point Likert scale: “I think of myself as an engineer.” The mean score before the program was 69%; the mean score after the program was 76%. Eighty-seven percent of these 34 students rated the statement higher after participating in the NM PREP program than they did before participating. Additionally, 69% of
the students said they would continue to participate in STEM activities in the future, and 76% stated an interest in returning to another NM PREP program. Finally, 87% of the students would recommend the program to a friend, which indicates an affinity for the program.

Another goal of the NM PREP program is to enhance students’ awareness about engineering career opportunities and possibilities. Once again, the program showed potential in this regard, with 74% of the students interested in pursuing a degree in STEM. In addition, 64% of the students planned to participate in STEM-based extra-curricular activities during the upcoming school year. One other interesting finding was that 23% of the students were interested in STEM-based school activities, but lacked necessary information. Therefore, it is critical to inform interested students about all of the STEM options and opportunities located in their areas.

Further evidence that the NM PREP program had an impact on the students was the increase in understanding of what engineers actually do. Students were asked on the pre-survey and the post-survey: “What do you think the following engineers do on a daily basis? If you don’t know, just put ‘I don’t know.’” The post-survey answer was compared to the pre-survey answer and reviewed for each student to conclude whether or not the student’s understanding increased during the program. Table 2 shows the percentage of students who demonstrated increased understanding of the duties of each type of engineer.

Table 2: Percentage of students who improved their understanding of various engineering disciplines using a Likert Scale responses.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Percentage (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey Engineer</td>
<td>94% (32)</td>
</tr>
<tr>
<td>Chemical Engineer</td>
<td>88% (30)</td>
</tr>
<tr>
<td>Civil engineer</td>
<td>74% (25)</td>
</tr>
<tr>
<td>Mechanical Engineer</td>
<td>74% (25)</td>
</tr>
<tr>
<td>Aerospace Engineer</td>
<td>68% (23)</td>
</tr>
<tr>
<td>Engineering Technology-Civil Engineer</td>
<td>68% (23)</td>
</tr>
<tr>
<td>Industrial Engineering</td>
<td>65% (22)</td>
</tr>
<tr>
<td>Engineering Technology - Electronics Engineering</td>
<td>59% (20)</td>
</tr>
<tr>
<td>Engineering Technology - Mechanical Engineering</td>
<td>59% (20)</td>
</tr>
</tbody>
</table>

What was the best part of the NM PREP program and how can the NM PREP program be improved?

Forty-one percent of the students considered the learning activities to be the best part of the program. These activities included individual and group projects, field trips, and hands-on activities. Therefore, the active learning methods represented nearly half of the students’ favorite
features of the NM PREP program. Furthermore, with regard to improvements for next year, 23% of students asked for more hands-on activities and 15% asked for fewer lectures. It appears that the hands-on activities and active learning were more engaging than the lectures. This observation is critical because research has shown that students’ retention is superior when they are engaged and find relevance in their work\(^6\). Therefore, the teaching methods used throughout the program may potentially have an impact on content knowledge and possible confidence gains in relation to STEM fields.

**Discussion**

**Findings**

This program was designed to enhance the understanding of each engineering field along with inspiring high school students to pursue engineering as a professional career. Our analyses examined the impact of the NM PREP program over summer 2016 focusing on whether the program positively affected the students in relation to content knowledge, awareness, and engineering career prospects. The data showed a significant improvement in the content exam scores of the student, but did not show a significant increase in the confidence. Due to the low number of students who participate in this program, it is difficult to tell if these results reflect the efficacy of the program or just the lack of usable data points. The combination of the qualitative and quantitative analyses also suggest a link between the active learning-based components of the program and the students’ growth in knowledge, which is consistent with previous findings\(^5\).

**Limitations and Recommendations**

Although the NM PREP program had a positive overall impact on the students, as is the case for many programs, there are areas that remain to improve in relation to the program itself and to the analysis.

**Program Improvements**

- The promotion and advertisement of the NM PREP program leave room for improvement. Because of the goals of the NM PREP program is to reach as many students as possible and to increase the number of students enrolled, it is critical that students receive information about the program weeks before the first day. In addition, it would probably be efficient to promote the program through high-schools and teachers in order to maximize publicity.
- It seems that some of the STEM programs were overlapping. It is important to review dates of other programs and select a time period where students will be available to attend.
- Analyses have shown that students care about teaching strategies used during the program, especially strategies that involve active learning. Therefore, it would be interesting to have the professors delivering content during the program to be involved in the curriculum development.

**Improvements of Analyses**

First, a limited number of students could be identified as completing both tests (N=27), which made some of the responses lack relevance. It would be interesting to compare those results to
other larger and similar programs to make more secure affirmations. Through the implementation of this survey in other STEM outreach programs within the New Mexico State University College of Engineering and eventually to students in STEM programs throughout the University, the researchers are aiming to understand how different STEM programs affect different students. In total, 41 students were present on the first day of program and one of those students had to leave due to a medical issue. Unfortunately, of the 41 students who took both the pre-tests and the post-tests only 27 of the students’ data could be used for the quantitative analysis and 34 for the qualitative analysis due to improper filling out of the test sheets, typos when entering their student ID numbers or other various mistakes. For future data collection, especially due to our low number of students accepted, greater attention should be paid to the students’ entry of their ID numbers on both forms of the assessment.

Due to the fact that this was the first attempt at developing and using instruments to measure both content knowledge and self-efficacy, there is a great deal of room for improvement. For future studies, the team will have a clear idea about what is being measured which will help the research team develop more accurate instruments. This pilot study has allowed the team to analyze which questions and responses are relevant and which ones are not. Moreover, the sections “please, explain” will be adjusted to gather more relevant information.

Additional questions will also be added to future surveys based on current research. Estrada et al.² suggests that self-efficacy becomes a poorer predictor of intention to participate in STEM programs when identification as a scientist and internalization of values are taken into account. Further studies in this area, including subsequent NM PREP program surveys, should include questions to gauge these other possible predictors as well as other possible variables. Duckworth et al.⁸ have studied grit and perseverance in the passion to pursue long-term goals. The addition of questions to gauge grit or perseverance (or both) into the survey could greatly improve predictive nature of these tools in terms of intention of students to pursue degrees and careers in STEM fields.

The data from this study have shown some promising results in regards to the efficacy of the program in improving the overall confidence and knowledge of the students in engineering. Along with the results of McClary et al.⁹ in the middle school program of the same name, the NM PREP program looks to be a viable program for encouraging and preparing young students for the rigors of pursuing a STEM–based college degree, and eventually, a career in STEM though further studies are planned and should be examined to solidify these findings.
References