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

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Abstract

Studies have shown that self-efficacy is a particularly important variable in the performance of students from underrepresented backgrounds, including females, and African American, Native American, and Hispanic students[7]. Self-efficacy has been shown to be a reliable predictor of academic performance and likelihood to pursue technical and scientific careers[6], and in many cases has been studied as a predictor of test scores[4]. The vast majority of self-efficacy studies have focused on long-term interventions based on academic performance[5]. This paper will present findings from a two-week STEM intervention on confidence and STEM knowledge among middle school participants. The paper will further explore the relationship between these variables and significant increases in either knowledge-based content exam scores or confidence survey scores pre- and post-program participation.

Key Words

K-12 Pre-College, STEM Intervention, Underrepresented Populations

Introduction

Self-efficacy has long been studied as a predictor of people's mental and physical performance. Bandura[2] 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[4]. In an academic context, self-efficacy has been shown to reliably predict academic performance and the likelihood of pursuing technical and scientific careers[6]. 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[7]. The majority of these studies that describe the 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 middle school students—The 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. Our specific research questions were as follows:

1. Did the confidence and/or content knowledge of the students change during the PREP 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 and/or confidence?

4. Did the PREP program impact a students' inclination to participate in additional STEM activities and/or pursue engineering as a career?

Program Background

Table 1: Sample Daily Schedule for the NM PREP Middle School Academy.

Time	Activity
7:00 am – 8:00 am	Breakfast
8:00 am – 10:00 am	Civil Engineering/ Bridges Lecture
10:00 am – 12:00 pm	Bridge Design (paper)
12:00 pm – 1:00 pm	Lunch
1:00 pm – 3:00 pm	Balsa Wood Bridge Building
3:00 pm – 5:00 pm	Bridge Strength Testing
5:00 pm – 6:00 pm	Dinner
6:00 pm – 8:00 pm	Exploratory Activity (LCPS Challenger Center for Space Science Education)
8:00 pm – 9:00 pm	Reflective/Down Time
9:00 pm	Lights out/ Bed Time

The NM PREP Academy is a two-week residential, immersive engineering education program where students are fully immersed in an engineering curriculum from 8:00 am to 5:00 pm. Beyond the engineering curriculum, the participants also engaged in exploratory activities designed to improve teamwork, leadership, and to expose the students to various experiences similar to beginning college engineering students, including lectures and design challenges. Students designed and built bridges, explored electrical networks, created posters, and had a poster session where they presented in an environment similar to a professional conference. The instructors for the lectures and design challenges included 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 director of the program and was also responsible for the exploratory activities that took place after hours. The daily curriculum was delivered by a local middle school science teacher. The students spent roughly one-third of every day attending lectures and two-thirds of the day doing hands-on and exploratory activities. A sample day is given in Table 1.

Curriculum

The PREP Middle School Academy curriculum was designed by the Engineering New Mexico Resource Network staff (a division of the NMSU College of Engineering focused on providing engineering-based outreach and community service throughout the state of New Mexico) utilizing feedback provided by the involved faculty members. The PREP Academy Program Manager met with members of the NMSU Engineering faculty to come up with activities and the science behind them to introduce students to the various engineering disciplines offered through the NMSU College of Engineering. Each department provided an activity that they thought would best engage students while providing them with some key skills needed to be successful as future engineering students. The activities were then carefully researched and tested by the PREP engineering work-study team to provide additional information for each subject and ensure each activity was appropriate for middle school students and could be completed, given time constraints.

Participants

The participants for this study were taken from the NM PREP Middle School Academy and consisted of students from grade six through grade eight. Of the 49 students who participated in the camp, 19 were female and 30 were male Ages ranged from 11 to 14 years of age. The participant ethnicity breakdown was as follows: 25 Hispanic, 16 Caucasian (non-Hispanic), four American Indian, two Asian/Pacific Islander and two African American participants. The majority of the participants (37) were from public schools, with seven participants from charter schools, one private school student and one homeschooled student (three students failed to respond to this question). Twenty-eight of the students were from urban areas, 13 from rural communities, and four from suburban communities (four students failed to respond to this question). The 49 participants were selected from over 170 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 an essay question designed to gauge the interest level and aptitude of the students.

The participants and their parents were asked to sign a consent form upon check-in to the academy which outlined 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 of the participants in each group finished their respective tasks, they 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 to test students' knowledge of the material covered in the camp. The exam measured engineering vocabulary, problem solving, and technical skills. The test had 91 possible points (67 vocabulary, 19 technical skills, and five problem solving). Each question had a value of one point and the total score was the number of correctly answered questions.

Survey

The self-efficacy survey was created using Survey Monkey. It 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 camp. Students were also 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 PREP experiences. Finally, in open-ended questions, students were asked about the "best" part of the program and what improvements could be made.

Analyses

Of the 49 students who participated, 46 took the content knowledge exam before and after the camp. The exam provided scores in three content knowledge categories: (1) vocabulary, (2) problem solving, and (3) technical skill. Of the students in the camp, 48 completed the self-efficacy survey before and after the camp. (One student completed the self-efficacy survey before the camp, but not after the camp.) 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 49 students that participated in the camp, 45 students completed the content knowledge exam and the self-efficacy survey both before and after the camp. The analyses reported below are based on data obtained from those 45 students.

We were especially interested in determining the efficacy of the academy in terms of two variables—(content) knowledge and confidence. Difference scores (posttest minus pretest), 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 until reaching agreement. Finally, frequencies of individual responses belonging to each category were counted.

Survey Question Results

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

Students' overall confidence (Figure 1) and knowledge (Figure 2) clearly increased, as evidenced by significantly positive gains in confidence (M = 6.64, $t(44)$ = 4.16, $p < .001$) and knowledge (M = 6.87, $t(44)$ = 3.59, $p < .001$).

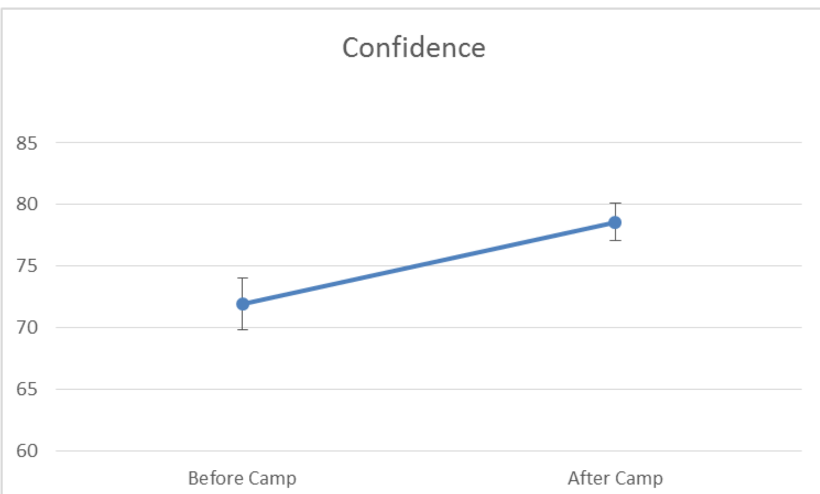

Figure 1. The change in confidence scores on self-efficacy surveys given before and after the camp to the 45 middle-school students included in these analyses. Error bars represent one standard error of the mean above and below their respective sample means.

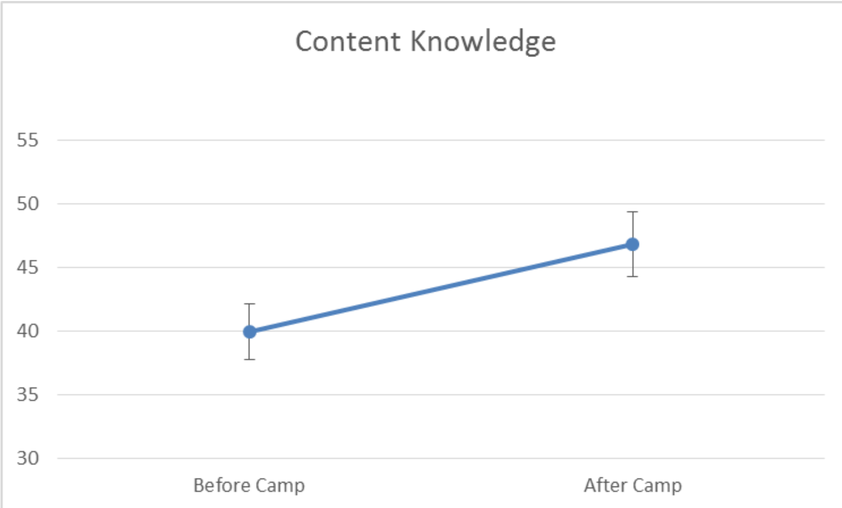

Figure 2. The change in scores on engineering content knowledge exams given before and after the camp to the 45 middle-school students included in these analyses. Error bars represent one standard error of the mean above and below their respective sample means.

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 science concepts. Eighty-two 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 camp on knowledge and confidence separately, we were interested in a possible relation between knowledge and confidence. However, we did not find a significant correlation between overall knowledge and confidence in the pretest scores (r = -0.16, $t(43)$ = 1.06, p = .852, ns) or the posttest scores (r = -0.02, $t(43)$ = -0.16, p = .562). Nor did we find a significant correlation between overall changes in knowledge and confidence (r = 0.06, $t(43)$ = 0.42, p = .338, ns).

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

We may describe the active learning that took place during the PREP academy as "having students engage in some activity that forces them to reflect upon ideas and how they are using those ideas," along with "keeping students mentally, and often physically, active in their learning through activities that involve them in gathering information, thinking, and problem solving" (Collins & O'Brien, 2003, p. 5). In more specific terms, the active learning experience cited by students referred to individual and group projects, hands-on activities and experiments, as well as field trips.

Of the 45 students included in the analyses, 29 (64%) mentioned an active learning method as the best part of the program. Furthermore, 16% of the students wished to see both more hands-on learning and less lecture during the academy. To explore more thoroughly the potential benefit of implementing curricula that emphasize active learning, we looked at students' changes in confidence and knowledge each as a function of whether they fell into the group that mentioned active learning. The change in confidence (M = 8.90) for those that mentioned active learning was significantly greater than the change in confidence (M = 2.56) for those that did not ($t(37.5) = 2.10$, $p = .021$). (See Figure 3.) However, the change in knowledge (M = 8.38) for those that mentioned active learning was not significantly greater than the change in knowledge (M = 4.13) for those that did not mention active learning ($t(18.7) = 0.88$, $p = .196$, n.s.). (See Figure 4.)

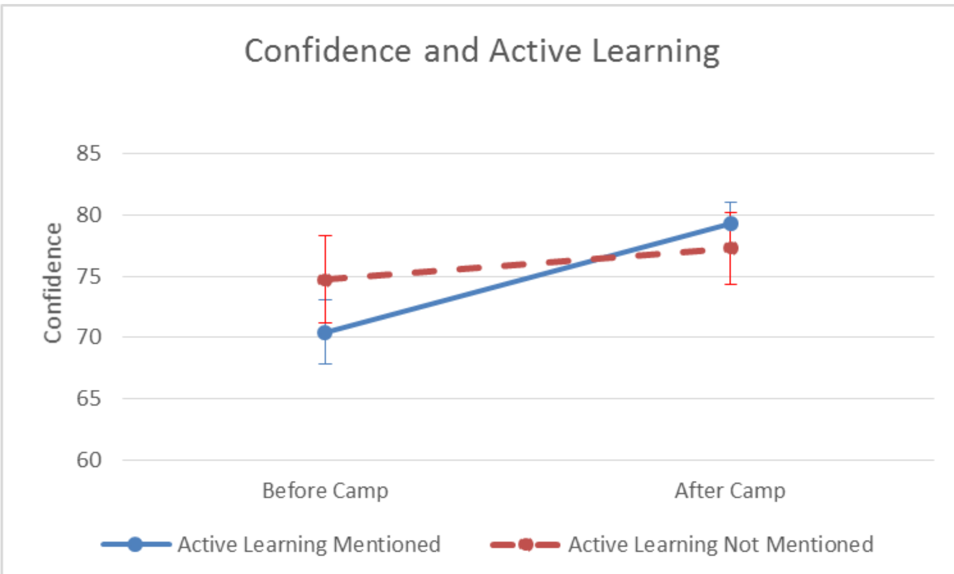

Figure 3. The change in confidence scores on self-efficacy surveys given before and after the camp for the 29 middle-school students who indicated an active learning component as the best part of the PREP program versus the 16 students who did not cite an active learning component. Error bars represent one standard error of the mean above and below their respective sample means.

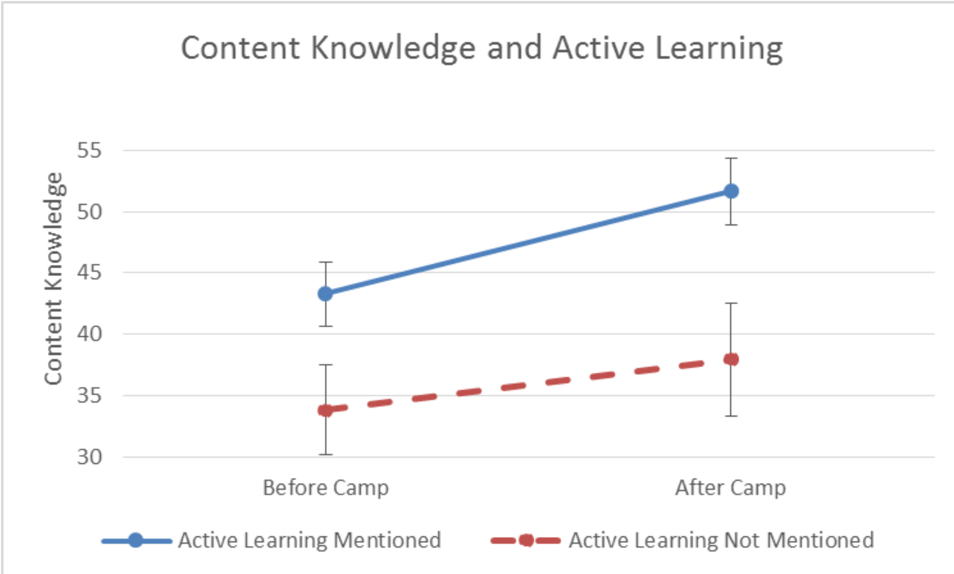

Figure 4. The change in scores on engineering content knowledge exams given before and after the camp for the 29 middle-school students who indicated an active learning component as the best part of the PREP program versus the 16 students who did not cite an active learning component. Error bars represent one standard error of the mean above and below their respective sample means.

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

An important goal of the NMSU 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, 75% 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 camp was 3.47; the mean score after the camp was 3.96. Twenty-three (51%) of these 45 students rated the statement higher after participating in the PREP program than they did before participating. Additionally, 67% of the students said they would continue to participate in STEM activities in the future And 76% stated an interest in returning to another PREP program. Finally, 96% of the students would recommend the PREP program to a friend.

Further evidence that the 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 camp. 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 the job duties of various engineering disciplines using an open-ended structure.

Engineering Disciplines	Percentage (# of students) N=49
Civil Engineer	92% (45)
Survey Engineer	71% (35)
Chemical Engineer	70% (34)
Aerospace Engineer	63% (31)
Mechanical Engineering	61% (30)
Engineering Technology-Electronics Engineering	51% (25)
Industrial Engineering	47% (23)
Engineering Technology- Mechanical Engineering	45% (22)

Findings

Our analyses examined the impact of the NMSU PREP program over summer 2016. This program was designed to enhance the understanding of each engineering field, along with inspiring middle school students to pursue engineering as a professional career. Our analyses determined whether the program positively affected the students in relation to content knowledge, awareness, and career prospects in relation with engineering. Table 2 shows the percentage of students whose understanding of the various engineering disciplines increased based on the qualitative analysis of the open-ended questions. Though it is unclear at this point why the number of students who showed improvement was so much greater for the Civil Engineer category, it was hypothesized by the researchers that many of the students didn't know much about Civil Engineering upon entering the camp. The only categories in which more students answered "I have no idea what this person does" on the pre-camp survey were the three Engineering Technician disciplines and Survey Engineering; these four disciplines were not covered in the same detail as the other disciplines in the camp. Further analyses could shed more light on this discrepancy.

With regards to the overall program experience, the majority of students perceived the NMSU PREP program as a positive experience. As a result, 96% of the students were willing to recommend the NMSU PREP program to a friend and 76% were interested in coming back next year.

Another goal of the NMSU PREP program is to enhance students' awareness about engineering career opportunities and possibilities. Once again, the program showed potential in this regard, with 73% of the students interested in pursuing a career in STEM. In addition, 67% of the students planned to participate in STEM-based extra-curricular activities during the upcoming school year. Finally, notice that 21% of the students were interested in extra school activities in relation to STEM but lacked necessary information. Therefore, it is critical to inform interested students about the options and opportunities located in their areas.

Furthermore, it is important to notice that some teaching methods had a stronger impact on the students. First, 64% 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 two-thirds of the students' favorite feature of the NMSU PREP program. On the other hand, 16% students asked for more hands-on activities and for fewer lectures with regards to improvements for next year. In conclusion, the way students are being taught plays an important role. It appears that hands-on activities and active learning made the students more engaged compared to lectures. This observation is critical because research has shown that students' retention is superior when they are engaged and find relevance in their work. Therefore, the teaching methods used throughout the program may potentially have an impact on content knowledge and confidence gains in relation to STEM fields.

The open-ended section of the survey appeared to be too broad and generic in regards to the analysis. It would be recommended to provide further guidance and explanations in order to direct students' responses and collect more precise information. Often time, their answers were very vague, which inhibited any further conclusions and resulted in broad responses lacking specificity towards the question asked.

The qualitative section of the research highlighted the importance of active learning and its impact on students. On the other hand, it seems that the development of instruction method has not been deepened as much as it should have, considering the degree of impact it appears to have on the students. Therefore, in order to enhance both knowledge retention and engagement, it is recommended to carefully plan how the instruction will be delivered.

Limitations and Recommendations

Although the NMSU PREP Academy had a positive overall impact on the students, as is the case for many camps, there are areas that remain to be improved in relation to the program itself and to the analysis. First, the program involved a limited number of students (N=49), 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 NMSU 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.

Moreover, the survey analysis could be more productive and accurate. It would be interesting to have a clear idea in mind of what is being tested through the survey in order to focalize the questions on this objective. This pilot analysis should help towards this goal by analyzing, which questions and responses are relevant and which ones are not. Moreover, the sections “please, explain” should be reviewed. Although it leaves room for criticism and ideas, some of the responses were too broad to be efficiently studied and reviewed. Thus, it would be better to provide more guidance by asking more specific questions. Estrada et al.[4] 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 PREP Academy surveys should include questions to gauge these other possible predictors as well as other possible variables. Duckworth et al.[3] 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.

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Tony McClary

Tony McClary is a graduate research assistant for the Engineering New Mexico Resource Center working in K-12 STEM Outreach. He received his bachelor's degree in Kinesiology with a focus in performance psychology from New Mexico State University and is a candidate for his Master's degree in Curriculum and Instruction with a minor in Physics from the NMSU College of Education. Tony has worked with the College of Engineering in the design and implementation of the NM PREP Academy and with the implementation of the BEST Robotics competition. Tony is also working with the College of Engineering on the development of a comprehensive assessment designed to understand the efficacy of the various STEM outreach programs in preparing students for collegiate success and design of future K-12 outreach programs.

Germain Degardin

Germain Degardin is a native of France and is currently a graduate student in Curriculum & Instruction. He arrived in Las Cruces in 2011 to pursue a BA in Economics and received an athletic scholarship to play for the NMSU Men's Tennis Team. After graduating with a BA in 2014, he decided to enroll in the MBA program, which he completed in spring 2015. He intends to graduate within 3 years with a license in secondary education and a license to teach French and Spanish at the high school level. He is also very interested by continuing his education by pursuing a Ph.D. in Education Leadership.

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John Kulpa is a PhD candidate in psychology at New Mexico State University, with minors in mathematics and applied statistics. As a member of NMSU's STEM Outreach Alliance Research Lab he provides guidance in research design and statistical analysis to educational outreach programs. His dissertation research is focused on developing automated, efficient methods of measuring people's subjective judgments of similarity.

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