OPPORTUNITIES FOR CREATIVITY AT A STEM SUMMER CAMP:

ARTICLES ON PARTICIPANTS' EXPERIENCES

A Thesis

by

LAURA ELIZABETH REEVES

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Chair of Committee,	Robert M. Capraro
Committee Members,	Mary Margaret Capraro
	Patricia Lynch
Head of Department,	Michael A. de Miranda

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ABSTRACT

In the two present studies that comprise this thesis, the researcher observes participants between ages 12-17 in two STEM (Science, Technology, Engineering, and Mathematics) summer camp sessions, both held at the same southeastern Texas university. The first present study concerns the effects of CAD software and a STEAM survey on participants' visual-spatial and creative abilities. The second present study aims to compare how the participants perceived creativity in STEM before and after attending the STEM summer camp. It also identifies which types of specific creative activities were preferred by these middle and high school participants. The results in both studies were analyzed by the entire set of participants, by gender, and by ethnic group. The 3D CAD software did not improve the visual-spatial skills for any of these classifications of participants; however, it seemed to positively affect males' creative actions. Females, males, and Blacks preferred "Bridge Building" as their most creative activity. Asians/Indians, Hispanics, and Caucasians/Whites, on the other hand, preferred "3D Printing/Modelling" as their most creative activity. These insights could aid in future research about diverse secondary students' recruitment and retention in STEM classes and fields.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a thesis committee consisting of Professor Robert M. Capraro, Professor Mary Margaret Capraro, and Professor Patricia Lynch.

The data analyzed for the articles comprising the thesis was provided by Professor Robert M. Capraro through the Aggie STEM Center of Texas A&M.

All other work for the thesis was completed independently by the student.

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CHAPTER I:

INTRODUCTION

Intentions

I plan to publish this thesis in the form of two journal articles rather than the traditional Master's thesis format. As these two articles will center on opportunities for creativity that two sets of secondary students experienced at a STEM (Science, Technology, Engineering, and Mathematics) summer camp, I will combine them into a single work. The first article, "Impact of 3D CAD Software on the Creative and Visual-Spatial Abilities of Secondary School Students", will be focused on opportunities for secondary students' development of creativity and visual-spatial skills through learning Computer Aided Design (CAD) software. The second article, "Secondary Students' Perceptions about the Arts and Creativity in STEM", will focus on the same secondary students' perceptions of and preferences for the types of STEM-related creative opportunities offered at the summer camp.

Background

While other research has focused on creativity in STEM, the majority have used measures examining general concepts of creativity, such as divergent thinking, rather than specific types of creativity or activities that involve creative thinking. Additionally, these articles tended to focus on college students rather than secondary students; those that do focus on secondary students usually do so only in terms of gender and age. My research expanded on previous research about creativity in STEM. In the first article, I examined pre-test and post-test results for secondary studies who took a course in CAD software during the summer camp as well as a STEAM survey. Both of these data sets helped me obtain a more encompassing picture of the relationships among creativity, spatial skills, and CAD software for secondary students. In the second article, I measured the frequencies of the specific STEM camp activities that the students cited in a STEAM survey and employ that data to pinpoint the creative activity preferences of the students by gender and ethnic group.

During the analysis of the pre-test and post-test for spatial visualization, the Cronbach's Alpha was 0.670. While this reliability is not "good," it is still acceptable for this type of educational research. Cronbach's Alpha or coefficient alpha measures how consistently participants respond to one set of items; it is almost an average of the correlations between items participants respond to in one set of items. The more the scores are spread out, the higher the reliability. The expectation is that scores become more homogeneous. In other words, the instruction was intended to narrow differences among the group, not maximize differentiation among those who know the content better than others. The pre-test and post-test for spatial visualization have been checked for validity through confirmatory factor analysis.

During the analysis of the pre-camp and post-camp STEAM survey questions 1-4 together, the Cronbach's Alpha was 0.710. This result indicated that the test had satisfactory reliability –the questions "work well" together to form an appropriate analysis. The only question that would raise the Cronbach's Alpha if deleted was pre-camp question 2. The pre-camp and post-camp STEAM surveys have been checked for validity through confirmatory factor analysis.

CHAPTER II:

ARTICLE 1

Some researchers have asserted that modelling with 3D Computer Aided Design (CAD) software could help improve students' spatial visualization skills and creative potential. This present study observes the effects of CAD software and a STEAM survey on two STEM summer camp sessions, both held at the same southeastern Texas university and involving participants between ages 12-17. The results for each session were analyzed as a single group, by gender, and by ethnic group. The 3D CAD software did not improve the visual-spatial skills for any of these classifications of participants, however, it seemed to positively affect males' creative actions, but a pre-camp bias towards creativity for all participants may have confounded that finding.

Article 1: Impact of 3D CAD Software on the Creative and Visual-Spatial Abilities of Secondary School Students

"Innovation experiences can influence STEM-related learning and career goals" in students in the middle grades (Small, 2014, p. 17). High school students could benefit even more from such experiences because they will soon enter college or the workforce. Before students can become innovative, however, they must engage in creative problem solving. They must also possess the visual-spatial skills necessary for putting their innovative ideas to paper (Aldous, 2007). Experiences with 3D Computer Aided Design (CAD) software could potentially bolster creativity and visual-spatial skills. Although 3D CAD software has been used in secondary school classrooms since the early 2000s, it has become more popular and more widely available due to the increased affordability of 3D printing.

CAD Software and Creative Problem Solving

Creativity, one of the most in-demand skills to potential employers (Pink, 2006), has gained widespread appeal in the second decade of the millennium (Hmelo, 1998). When CAD is used for designing, "it is possible to observe and record instances of the behaviors that cognitive psychologists have associated with creativity" (Musta'amal, Norman, & Hodgson, 2009, p. 64). In fact, it has been shown that 3D CAD software enhanced high school students' creative performance (Chang, 2014). The 3D CAD software proved especially relevant for the physical appearance of the model. Google Sketchup® was shown to have a positive effect on the fluency and flexibility of thought—two important measures of creativity—on high school freshmen (Liveri, Xanthacou, & Kalia, 2012).

Middle and high school students are more inclined towards divergent thinking than elementary school students (Ma, 2006), so they are more creative in that sense. Divergent thinking, or coming up with multiple possible solutions to a problem, contains three elements: fluency, flexibility, and originality of thought processes (Madden et al., 2013). Designing products in a virtual space in which students can "test" multiple ideas helps them develop these qualities. Females perform better in artistic creativity (e.g. the aesthetics of design) than males, although no noteworthy differences were found between females and males in scientific creativity (e.g. problem solving) (Kozhevnikov, Kozhevnikov, Yu, & Blazhenkova, 2013). Having an external aid, such as CAD software, in which to visualize possibilities also reduces students' working memory (Weisberg, 2006). Such a reduction facilitates students devoting more of their energy to creative thought.

Middle and high school students also tend to rely more on one another for feedback than the teacher. This kind of support is necessary for both individual and collective creativity to flourish (Fischer, Giaccardi, Eden, Sugimoto, & Ye, 2005). Teachers can and should recognize and foster students' creative potential, especially during building and designing activities (Hathcock, Dickerson, Eckhoff, & Katsioloudis, 2014). A classroom of students eagerly working together on CAD models provides an environment conducive to innovative thinking and problem solving.

Students should not depend exclusively on CAD software to express their creativity in design, though. One study suggested that the models students create in CAD software may actually impede their creativity in the real world of engineering. These idealized virtual sketches may not necessarily translate into a product in industry, as the process of product formation involves flexibility and a working knowledge of components and materials (Robertson, Walther, & Radcliffe, 2007). A survey of engineers concluded that CAD software assisted with creativity and visualization in the more mature stages of design, but that more traditional methods, such as free-hand sketching and verbal discussion, had proven more helpful during the initial stages of design (Robertson & Radcliffe, 2009). These studies indicated that 3D CAD software remained but one of many tools students used to guide their creative thinking.

CAD Software and Visual-Spatial Ability in General

Modeling in 3D CAD software has been shown to improve various spatial visualization abilities of secondary students and college students. Teaching students engineering drawing skills with 3D CAD could improve students' ability to think visually in three dimensions (Ziden, Zakaria, & Othman, 2012). Short remedial classes in engineering design using Google Sketchup® resulted in large, measureable gains in mental rotation and spatial visualization for freshman civil engineering students (Martin-Dorta, Saorin, & Contero, 2008). However, before students can model effectively in CAD software, they first needed to become familiar with 3D objects through physically manipulating and sketching them (Chester, 2008; Robertson, Walther, & Radcliffe, 2007).

Chang's (2014) study indicated that students with higher spatial ability performed better on measures of creativity than those with lower spatial ability. The results suggested that the ability to visualize a product might contribute to success with the 3D CAD software and not the other way around (Erkoç, Erkoç, & Gecü, 2013). They studied the effect of Google Sketchup® on eighth grade students and found no noteworthy differences between the mean scores of the experimental group (who drew unit cube models using Google Sketchup®) and control group (who drew unit cube models by hand) on the Mental Rotation Test. In other words, the effects of drawing virtually did not differ from the effects of drawing by hand.

CAD Software and Visual-Spatial Ability by Gender

Females have tended to lag behind males in visual-spatial skills due to a combination of biological (Moore & Johnson, 2008; Puts, McDaniel, Jordan, & Breedlove, 2008; Levine, Huttenlocher, Taylor, & Langrock, 1999) and sociological (Hyde, 2014; Lippa, 2002, as cited in Voyer, Nolan, & Voyer, 2000; Yilmaz, 2009;) factors. However, visual-spatial skills could also be taught and improved upon (Sorby, 1999; Uttal et. al., 2013; Yenilmez & Kakmaci, 2015). Logical thinking and reasoning skills were good predictors of high spatial performance for females on spatial relations tests (Kaufmaan, Steinbüg, Dünser, & Glück, 2004). Researchers have asserted that CAD software can improve those visual-spatial skills in females. In a sample of 8th grade students, CAD software not only improved the mental rotation and spatial visualization skills of the students as a whole, but also for the females verses the males; posttest scores for females were higher than those of the males (Toptas, Celik, & Karaka, 2012).

CAD software could prove one possible avenue through which females can better their visual-spatial ability.

Research Questions

(1) Can CAD software help improve spatial skills?

(2) Can males or females see greater pretest-posttest gains in terms of spatial skills?

(3) Can CAD software help improve creativity?

(4) Can a pre-camp bias for creativity in STEM affect post-camp results?

Methodology

Participants

Participants consisted of 25 females and 52 males ranging in ages from 12-17 who participated in a two-week summer camp at a research university in Texas. Of the females, 1 was Asian, 3 were Black, 2 were Hispanic, 12 were Caucasian/White, and 7 did not indicate their ethnicity. Of the males, 4 were Asian, 2 were Black, 30 were Caucasian/White, 15 were Hispanic, and 1 did not indicate his ethnicity. Informed consent was obtained from all the participants and their parents.

Instruments

Participants took a spatial visualization pretest before taking courses in CAD design and a spatial visualization posttest after taking courses in CAD design. Participants also took a required survey in which they self-selected their demographic information. The statistical software package SPSS 23 was used to store and analyze the data collected.

Procedure

During the summer camp, participants engaged in a course on Google Sketchup®, a CAD program used primarily for 3D printing, for 2 hours per day five days a week for two weeks. Before taking the course, participants were administered a test in spatial visualization. They were administered a similar spatial visualization test after taking the course as well. To determine whether CAD software helped improve spatial skills (Research Question #1), a paired-samples *t*-test was used to compare pretest and posttest mean scores for all participants. To determine whether females or males experienced greater pretest-posttest gains in spatial skills (Research Question #2), a paired-sample *t*-test comparing the pretest and posttest mean scores for females and a paired-sample *t*-test comparing the pretest and posttest mean scores for males will be used. Cohen's *d* effect sizes will be reported for the entire set of participants, for participants by gender, and for participants by ethnic group. To determine whether 3D CAD software improves students' creativity (Research Question #3), the types and natures of the comments on a STEAM (Science, Technology, Engineering, Art, and Mathematics) survey were analyzed for all participants, participants by gender, and participants by ethnic group. To determine whether a bias for creativity in STEM influenced the findings (Research Question #4), the researcher compared the changes in the means of the corresponding question pairs #1-#4 on the STEAM survey.

In the context of this present study, "creativity" has been defined as (a) creative problem solving—applying novel solutions to projects or problems, (b) aesthetic creativity—applying elegant solutions to products or problems, or (c) both creative problem solving and aesthetic creativity.

Results

Results for All Participants (RQ 1)

The mean score for all of the participants on the pretest was higher ($\bar{X}$=19.053; SD=6.366) than that for the same participants on the posttest ($\bar{X}$=17.276; SD=6.414). For the paired sample *t*-test, t= 2.433 and df=75. The Cohen's *d* effect size for all participants (d=0.278) indicated that taking a course in CAD software had a small negative effect on performance. This effect was also statistically significant (p = 0.017). These statistics suggested that the participants performed worse on spatial-visual tasks after the intervention. However, the course consisted of their first exposure to CAD software for the majority of the participants. The software's effect on their spatial-visualization skills may have been confounded by the cognitive load the participants expended on learning the software itself.

Results by Gender (RQ 2)

Neither gender's pretest/posttest results indicated growth in spatial skills directly from the 3D CAD software course. In fact, they seemed to the show the opposite effect: the 3D CAD software course interfered with the development of spatial skills. This effect, though, may not have had to do with the 3D CAD software directly; the same confounding factors that affected the results for the participants in general could have played a role.

Females. The mean score for females on the pretest ($\bar{X}$=16.000; SD=5.930) was higher than that for females on the posttest ($\bar{X}$=14.360; SD=5.417). For the paired sample *t*-test, t=1.431 and df=24. The Cohen's *d* effect size for female participants (d=

0.295) indicated that taking a course in CAD software had a somewhat greater effect on female participants than the total sample of participants. Unlike the effect of CAD software on the total sample of participants, the effect for female participants was not statistically significant (*p*=0.165). This result could have been affected by the CAD software course, but it could have also occurred solely by chance or by other variables that the researcher did not measure.

Males. The mean score for males on the pretest ($\bar{X}$=20.549; SD = 6.081) was higher than that for males on the posttest ($\bar{X}$=18.706; SD =6.531). For the paired sample *t-test, t= 1.962 and df= 50.* The Cohen's *d* effect size for males (*d*=0.292) was very close to that for females and somewhat larger than that for the total sample of participants. This finding suggested that the CAD software had a similar effect on both genders when treated separately but a slightly smaller effect when viewed as a whole. The difference was not statistically significant (*p*=0.06).

Results by Ethnic Group

The scores by ethnic groups were lower on the posttest than on the pretest. However, none of the effects was statistically significant. The result could have been due to the learning curve of the CAD software, but it more likely occurred by chance. The Pre-Camp STEAM Survey consisted of five questions on a four-point Likert scale, while the Post-Camp STEAM Survey consisted of four questions on a four-point Likert scale and a fifth open-ended question. The possible scores on the Pre-Camp survey ranged from 5 to 20. The possible scores on the Post-Camp survey ranged from 4 to 16.

Results for All Participants (RQ 3 and RQ 4)

No detectable mean changes occurred for the entire set of participants between each Pre-Camp/Post-Camp pair. This result indicated that the students already favored creativity in STEM before the summer camp.

Results by Gender

As expected, the 3D CAD software course influenced males' creativity but not females' creativity. The extent that the 3D CAD software course did or did not influence each gender's creativity, though, remains vague. Females tended to view creativity through 3D CAD software as a quality of the program, whereas males tended to view creativity through 3D CAD software as a process.

Females. Overall mean scores for females fell from 13.03 to 12.92. For the paired sample t-test, $t = 0.289$ and $df=33$. Mean scores for females dropped very little for each corresponding question pair except Pre-Camp/Post-Camp Question 3, where it rose from 2.53 to 2.74. The means tended to stay in the 3s, in the mid-to-high range of the 4-point Likert scale. All of the females wrote comments for Post-Camp Question 5; only 4 (11%) included 3D designing and printing in their comments on creativity.

The 3D CAD design aspect of the summer camp did not stand out to the females. It was just one of the many STEM-related activities in which they participated. One female commented that she used creativity when "[d]esigning on sketch up, making the commercial, trebuchet models, making cryptography codes." The nature of such comments remains consistent with the statistic that so few women cited 3D CAD design as a creative activity.

Males. Overall mean scores for males rose from 12.66 to 12.82. For the paired sample *t*-test, $t = -0.539$ and $df = 54$. The means tended to stay in the 3s, in the mid-to-high range of the 4-point Likert scale. Of the males who took the survey, 50 wrote comments for Post-Camp Question 5; of the 50 males, 11 (22%) included 3D designing and printing in their comments on creativity. The males' comments tended to be more detailed than the females' comments and focused more on creativity as a process rather than an attribute.

As with the females, the males expressed that they used creativity in 3D printing without defining the term. However, the males did describe what they did with their creativity in addition to naming the activity in which they used it: "I created a lot of different designs on sketch up using my creativity."

Results by Ethnic Group

The 3D CAD software course had the greatest positive influence on the Asian, Indian, and Hispanic participants. This effect was somewhat surprising, as Hispanic students typically grow at slower rates in STEM activities than Asian and Indian students. All other ethnic groups in the present study fared slightly worse after taking the 3D CAD software course than before taking the 3D CAD software course.

Asian. The overall mean for Asian participants rose from 14.50 (SD=0.837) to 15.12 (SD=1.329). The Pre-Camp confidence interval was 14.50 ± 0.67. The Post-Camp confidence interval was 15.12 ± 1.06. For the paired sample *t*-test, $t = -1.348$, $df = 5$, and $p = 0.235$.

Black. The overall mean for Black participants fell from 13.20 (SD=2.387) to 12.00 (SD=2.915). The confidence intervals for Black participants were wider than those of any other ethnic group in the study. The Pre-Camp confidence interval was 13.20 $\pm$ 2.09. The Post-Camp confidence interval was 12.00 $\pm$ 2.56. For the paired sample *t*-test, t =1.633, df=4, and p=0.178.

Caucasian/White. The overall mean for Caucasian participants fell from 12.61 (SD= 1.693) to 12.57 (SD= 2.102). The Pre-Camp confidence interval was 12.61 $\pm$ 0.47. The Post-Camp confidence interval was 12.57 $\pm$ 0.59. For the paired sample *t*-test, t = 0.121, df=48, and p=0.904.

Hispanic. The overall mean for Hispanic participants rose from 12.94 (SD=2.043) to 13.67 (SD=2.449). The Pre-Camp confidence interval was 12.94 $\pm$ 0.94. The Post-Camp confidence interval was 13.67 $\pm$ 1.13. For the paired sample *t*-test, t = -1.725, df=17, and p=0.103.

Indian. The overall mean for Indian participants rose from 11.00 (SD= 0.000) to 12.50 (SD=0.707). A Pre-Camp confidence interval could not be computed for the Indian participants. The Post-Camp confidence interval was 12.50 $\pm$ 0.98. For the paired sample *t-test*, *t = -3.000, df=1, and p= 0.205.*

No Ethnic Group Indicated (N/A). The overall mean for participants who did not indicate an ethnicity fell from 12.78 (SD=1.716) to 12.11 (SD=3.408). The Pre-Camp confidence interval was 12.78 $\pm$ 1.12. The Post-Camp confidence interval was 12.11 $\pm$ 2.23. For the paired sample *t*-test, t = 0.590 and df=8, and p=0.572.

Discussion

Can CAD software help improve spatial skills? The entire set of participants scored statistically significantly lower on the spatial visualization pre-test than on the spatial-visualization post-test. As previously stated, this effect could have been due to barriers in learning 3D CAD software rather than the software itself. These findings remain consistent with the literature, in which some researchers claim that students who use 3D CAD software perform on level or lower on spatial visualization measures compared to students who draw by hand (Erkoç et al., 2013).

Can males or females see greater pretest-posttest gains in terms of spatial skills? Surprisingly, neither gender made greater pretest-posttest gains than the other in terms of spatial skills. In fact, both genders' mean scores lowered somewhat after taking the course in CAD software. This finding seems to contradict the current literature, which states that females make greater gains than males after using CAD software (Toptas et al., 2012).

Can CAD software help improve creativity? The proportion of males who referred to 3D printing and CAD design as examples of using creativity in STEM (11/50 = 22%) was double that of females who referred to these examples (4/34 = 11%). 3D printing and CAD design clearly affected males' creativity more positively than females' creativity. This finding remains consistent with the literature, which states that males are more likely to engage in activities that involve spatial ability than females due to males' biological (Levine et al., 1999; Moore & Johnson, 2008; Puts et al., 2008) and sociological (Hyde, 2014; Lippa, 2002, as cited in Yilmaz, 2009; Voyer et al., 2000) advantages in visual spatial skills.

Can a pre-camp bias for creativity in STEM affect post-camp results? No detectable change occurred in any of the items. This result suggests that a Pre-Camp bias towards creativity in STEM existed for the total set of participants. Learning the 3D software had little effect on the participants' attitudes on creativity.

CHAPTER III:

ARTICLE 2

In this present study, the researcher aimed to compare how secondary students ages 12-17 perceived creativity in STEM (Science, Technology, Engineering, and Mathematics) before and after attending a two-week STEM summer camp at a research university in Texas. The researcher also aimed to identify which types of specific creative activities were preferred by each gender and ethnic group of these middle and high school participants. These insights could provide valuable information about the potential ways in which to engage secondary students—especially female, Black, and Hispanic secondary students—in STEM. The results for each session were analyzed by the entire set of participants, by gender, and by ethnic group. Females, males, and Blacks preferred “Bridge Building” and Asians/Indians, Hispanics, and Caucasians/Whites preferred “3D Printing/Modelling.”

Article 2: Secondary Students' Perceptions about the Arts and Creativity in STEM

Why do some individuals, or even some ethnic groups, value STEM while others do not? Some researchers cite the importance of parental involvement or the father's occupation; others rely on the students' abilities and experiences. All of these factors could explain secondary students' disparities in STEM interest and ability, but one factor still exists that has not yet been accounted for: students' perceptions of the creative and artistic aspects of STEM. "The arts encourage students to apply their arts-related intelligences to perceive and organize new information into concepts that are used to construct meaning" (Gullatt, 2008), so using creativity and the arts could spark interest in STEM for secondary students who may not have otherwise been interested in such subjects.

STEAM and Underrepresented Students

A lack of interest in STEM careers remains an important factor in the United States' STEM worker shortage—especially for the underrepresented populations of Blacks, Hispanics, and females. Unfortunately, this trend among underrepresented populations has begun to manifest itself in the early teenage years and has continued to spiral downward with age. Middle and high school students from these populations may discount STEM for a variety of reasons. They may wish to avoid the many negatives stereotypes associated with STEM subjects, particularly in mathematics (Deacon, 2012); feel under confident about their own abilities in STEM subjects (Nestor-Baker & Kerka, 2009); do not see role models of their own gender or race working in STEM professions

(Moody, 2004); or have low interest in STEM subjects or careers (Wang & Degol, 2013). Many Black and Hispanic students have been barred from STEM experiences outside of school due to low socioeconomic status. These experiences have tended to be longer and more engaging than those within school, but they have also come with high prices. However, if teachers implement STEM activities that engage students during this critical period of adolescence, then underrepresented and low SES populations are much more likely to matriculate into STEM subjects and into higher education.

The courses at the STEM summer camp in the present study consisted largely of Project-Based Learning (PBL) activities, in which participants were provided a specific objective and constraints for a project but were otherwise free to work on the project as they saw fit. This kind of freedom allows for much more creative problem solving and aesthetic creativity than more traditional direct instruction courses. PBL activities have been shown to benefit groups who are unrepresented in STEM: females, Blacks, and Hispanics.

Female secondary students. More males have taken higher-level STEM courses and have cited greater interest in STEM subjects and careers than females (Tyson, Lee, Borman, & Hanson, 2007). However, middle school female students have enjoyed more success than their male peers in tasks requiring creativity (Jaladanki, 2015) and have even outperformed males in three important measures of creativity: originally, flexibility, and fluency (Roue, 2014). Females who participated in STEM PBL made greater gains in science than those who do not participate in STEM PBL (Mehalik, Doppelt, & Schunn, 2008). These results suggest that females' interests in STEM could be increased if females had more opportunities to use creativity in STEM.

Black secondary students. The level of parental involvement, the father's occupation, and exposure to STEM play important roles in the disparity in interest and achievement between Black students and their peers. A positive correlation exists between these factors and achievement in mathematics, a foundation for many STEM fields, and Black students have less of each factor (Kim & Hocevar, 1998). However, they can and do succeed in STEM subjects if teachers make concepts tangible to them. Actively involving Black students in the learning process contributes to heightening their STEM interest.

After Black students engaged in a PBL robotics unit, in which they had to use their creativity to form the final products, they made large gains in science and even greater gains in mathematics than their Hispanic and Caucasian/White female peers. (Erdogan, Corlu, & Capraro, 2013). Artistic and creative activities not directly related to STEM have also improved Black students' motivation and achievement in mathematics. A study on Black students in St. Louis, Missouri, indicated that those who took art electives showed more improvement in their mathematics standardized test scores over two years than those who did not (Missouri Alliance for Arts Education, 2012).

Hispanic secondary students. Hispanic parents stress high expectations for their children and help children with their nightly homework. The STEM interest of Hispanic American students and Hispanic immigrant students, however, falters despite Hispanic parents' equally high expectations and involvement in their children's education as

Caucasian/White parents. The language barrier between Spanish and English could prove one of the stumbling blocks to Hispanic students' success in STEM subjects. Both Hispanic children and their parents, even those who have lived for years in predominately English-speaking cities in the United States, struggle with STEM subjects because they do not know the target language well enough to think their way through the material. This facet remains especially true in mathematics, which forms the foundations for success in many STEM courses and fields. The ability to reason through and communicate mathematical ideas effectively proves essential for learning mathematics (Campbell, Adams, & Davis, 2007; Civil, Planas, & Quintos, 2005).

However, Hispanics have also come from cultures in which the arts and creativity are highly valued. This facet could serve as a Hispanic advantage in STEM tasks with artistic or creative components. In a STEM activity on robotics, the Hispanic students formed more creative products than their non-Hispanic peers (Erdogan et al., 2013). Hispanic students, if given more such STEM opportunities, would not only be able to communicate their ideas non-verbally, but also showcase their talents in aesthetics and innovation.

Research Questions:

(1) Can integrating the arts into STEM increase underrepresented (female, Black, and Hispanic) participants' interests in STEM?

(2) Which creative STEM activities are most and least referred to by each gender as measured by the type of activity and the gender of the responder in the survey?

(3) Which creative STEM activities are most and least referred to by each ethnic group as measured by the type of activity and the ethnic group of the responder in the survey?

Methodology

Participants

Participants consisted of 35 females and 55 males ranging from ages 12-17 who participated in a two-week summer camp at a research university in Texas. Of the females, 4 were Asian/Indian, 4 were Black, 17 were Caucasian/White, 3 were Hispanic, and 7 did not indicate their ethnicity. Of the males, 4 were Asian/Indian, 1 was Black, 33 were Caucasian/White, 14 were Hispanic, and 3 did not indicate their ethnicity. Informed consent was obtained from all the participants and their parents.

Instruments

Participants took a survey on creativity in STEM before and after they attended the STEM summer camp. The statistical software package SPSS 23 was used to store and analyze the data collected.

Pre-Camp Survey. The pre-camp survey contained five questions measuring participants' perceptions on various aspects of creativity in STEM. Participated evaluated these questions with a 4-point Likert scale, with 1 corresponding to strongly disagree and 4 corresponding strongly agree.

Post-Camp Survey. The first four questions of the post-camp survey were identical to the corresponding questions in the pre-camp survey. Participants evaluated Post Camp Questions 1-4 with a 4-point Likert scale, with 1 corresponding to strongly disagree and 4 corresponding strongly agree. Participants provided an open-ended response to Post Camp Question 5 based on their experiences with creativity and STEM during the summer camp.

Procedure

To determine whether integrating the arts into STEM can increase underrepresented students' interests in STEM (Research Question #1), measures of growth between Pre-Camp Question #3 and Post-Camp Question #3 were analyzed and compared for (a) gender and (b) ethnic group through 95% confidence intervals and paired-sample *t*-tests. Female participants' growth was compared with male participants' growth; Hispanic and Black participants' growth was compared with Caucasian/White participants' growth.

To determine which STEM activities were the most and least referred to by gender (Research Question #2), all relevant mentions of activities in the comments were counted and placed within ten categories for each gender: Generic Comments on Creativity in STEM Activities, Bridge Building, 3D Printing/3D Modeling, Trebuchet, App Design, Cosmetic Chemistry, Print Marketing, Renewable Energy/Circuitry, Multimedia, and Other. Determining which STEM activities were the most and least cited by ethnic group (Research Question #3) was conducted in the same way, except the comments were placed within the ten categories for each ethnic group rather than for each gender.

Results

Results for Underrepresented Students (RQ 1)

Females. The mean difference for females (0.21) was slightly higher than the mean difference for the benchmark gender, males (0.20). The overall mean for female participants rose from 2.53 (SD=0.992) to 2.74 (SD=1.053). The Pre-Camp Question #3 confidence interval was 2.53 ± 0.33. The Post-Camp Question #3 confidence interval was 2.74 ± 0.35. For the paired sample t-test, t=-1.748, df=33, and p=0.090.

Black. The mean difference for the Black ethnic group (0.20) was higher than the mean difference for the benchmarked White/Caucasian ethnic group (0.08). The overall mean for Black participants rose from 2.60 (SD=1.342) to 2.80 (SD=1.304). The Pre-Camp Question #3 confidence interval was 2.6 ± 1.18. The Post-Camp Question #3 confidence interval was 2.8 ± 1.14. For the paired sample t-test, t= -1.000, df=4, and p=0.374.

Hispanic. The mean difference for the Hispanic ethnic group (0.50) was higher than the mean difference for the benchmarked White/Caucasian ethnic group (0.08). The overall mean for Hispanic participants rose from 2.56 (SD=0.984) to 3.06 (SD=0.938). The Pre-Camp Question #3 confidence interval was 2.56 ± 0.45. The Post-Camp Question #3 confidence interval was 3.06 ± 0.43. For the paired sample t-test, t=-3.000, df=17, and p=0.008. This result was statistically significant, as $p_{critical}$=0.05.

Results by Gender (RQ 2)

Females. All 35 females wrote comments for Post-Camp Question 5. In general STEM contexts, females tended to focus more on what they or their group members accomplished through creativity rather than the process of creativity itself. Although females specified the activities in which they used their creativity, the vast majority of them did not mention what creativity meant to them. One female participant stated: “In the renewable energy class we were able to be creative in how we set up the solar panel, and it was extremely rewarding when it worked. We also used creativity in building our bridge.”

Females mentioned the Bridge Building activity the most frequently (12 times) in their comments about opportunities for them to use creativity during the STEM summer camp. Interestingly, females mentioned the Cosmetic Chemistry activity the least frequently (3 times), along with activities in the “Other” category.

Males. The most detailed and articulate comments concerned how males felt about creativity in STEM rather than during specific STEM activities. One male participant stated: “Creativity to me isn't about being artsy but more about thinking outside the box; except on a dramatic level. The world couldn't have advanced without daring risks and that to me is creativity. So I would try to think of the best and fastest way to go about a project but give it the most unique aspects I could.”

Males mentioned the 3D Printing/Modeling activity the most frequently (18 times) in their comments about opportunities for them to use creativity during the STEM summer camp.

Results by Ethnic Group (RQ 3)

Asian/Indian. Of the 8 Asian/Indian participants in this present study, 7 wrote comments for Post-Test Question 5. Creativity in general STEM contexts was mentioned only once. Of their uses of creativity within specific STEM activities, Asian/Indian participants mentioned “3D Printing/Modeling” the most (3 times). They did not mention “Trebuchet” or “Cosmetic Chemistry” at all.

Black. Of the 5 Black participants in this present study, 4 wrote comments for Post-Camp Question 5. Black participants commented 2 times on creativity in STEM in general. Black participants mentioned “Bridge Building” (mentioned 1 time) and activities in the “Other” category (mentioned 1 time) as the specific STEM activities in which they used creativity.

Caucasian/White. Of the 50 Caucasian/White participants in this present study, 45 wrote comments for Post-Camp Question 5. Caucasian/White participants mentioned creativity in general STEM contexts 8 times. Of their uses of creativity within specific STEM activities, Caucasian/White participants mentioned “Bridge Building” the most (14 times) while they mentioned “Cosmetic Chemistry” the least (2 times).

Hispanic. All 18 Hispanic participants in this present study wrote comments for Post-Camp Question 5. Of all the ethnic groups’ comments, those of the Hispanic participants were the most diverse and articulate. Hispanic participants also mentioned creativity in general STEM contexts 10 times, which was 30% more often than the most cited specific STEM activity: “3D Printing/Modeling.” Hispanic participants cited “Renewable Energy/Circuitry” the least.

No Ethnic Group Indicated (N/A). Of the 10 participants who did not indicate an ethnic group in this present study, 8 wrote comments for Post-Camp Question 5. They mentioned creativity in general STEM contexts 4 times. Participants who did not indicate an ethnic group most mentioned “Bridge Building” (4 times) as the specific STEM activity in which they used their creativity. They mentioned “3D Printing/Modelling,” “Trebuchet,” and “Multimedia” 1 time each, and they did not mention the other activities.

Discussion

Can integrating the arts into STEM increase underrepresented (female, Black, and Hispanic) participants' interests in STEM? Integrating the arts into STEM increases all underrepresented participants' interests in STEM, but especially for Hispanic participants. The camp activities had a statistically significant effect on Hispanic students' uses of creativity in STEM. "3D Printing/Modeling" was the most notable.

Which creative STEM activities are most and least referred to by gender?

Female participants. Female participants referred to "Bridge Building" the most and "Cosmetic Chemistry" the least. This result may initially seem surprising, as cosmetics are thought to appeal widely to females. However, upon closer inspection, one can see that this result is consistent with prior research on females' creativity. Females tend to express their creativity in terms of aesthetics more so than in terms of problem solving, and the "Bridge Building" activity concerns itself highly with the appearance as well as the function of the bridge. Female participants did not mention "Multimedia" and "Other" activities at all.

Male participants. Male participants referred to "3D Printing/Modelling" the most and "App Design" the least. This result was expected, as "3D Printing/Modelling" involves much creative problem solving and visual-spatial skills—two areas in which males have traditionally surpassed females. "App Design" concerns itself mostly with aesthetic creativity, an area in which males have performed below females. Not one male participant mentioned Cosmetic Chemistry as an opportunity for them to use creativity during the STEM summer camp. The reason for this nonexistent mentioning could not have been for the male participants to save face with their peers; the survey and its comments were confidential and taken online. It seemed that the male participants genuinely did not perceive Cosmetic Chemistry as an opportunity that engaged their creative energies.

Which creative STEM activities are most and least referred to by ethnic group?

Asian/Indian participants. Asian/Indian participants mentioned “3D Printing/Modeling” the most. This result remains consistent with both past research and cultural norms for Asians/Indians. Asian and Indian cultures place a high value on order within the arts, and “3D Printing/Modeling” depends on these same aesthetic tendencies. Therefore, Asians/Indians may have referred to “3D Printing/Modeling” the most because it reflects their cultural understandings of aesthetic creativity.

Black participants. Black participants mentioned “Bridge Building” and activities in the “Other” category as the specific STEM activities in which they used creativity. This result also remains consistent with past research. Black students learn best when they can creatively problem-solve through hands-on activities. The “Bridge Building” PBL allowed them to do just that through constructing a Popsicle stick bridge within various weight and materials constraints. The next-most cited category, “Other,” indicated that the Black participants had diverse creative interests not only from their non-Black peers, but also from one another.

One caveat to these findings was that there were only 5 Black participants in the present study. The small subsample size may have confounded the results for this ethnic group. Therefore, these results may not be generalizable to all Black secondary students in Texas. The Black students who attended the STEM summer camp may have already enjoyed or experienced STEM and STEM PBL activities before coming to the camp.

Caucasian/White participants. Caucasian/White participants mentioned "Bridge Building" the most while they mentioned "Cosmetic Chemistry" the least. These results remain unsurprising, as the majority of the Caucasian/White participants were males who enjoyed hands-on activities through which they could creatively problem-solve. The Caucasian/White males in the study were also genuinely uninterested in "Cosmetic Chemistry" as an outlet for their creativity, and most of the Caucasian/White females were uninterested in it as well.

Hispanic participants. Hispanic participants mentioned "3D Printing/Modeling" the most and "Renewable Energy/Circuitry" the least. This finding remains consistent with prior research. Due to language and cultural barriers, Hispanic students need a way to express their creative problem-solving abilities non-verbally. Building a Popsicle stick bridge could be one such avenue. Although the Hispanic participants needed to communicate with team members during the bridge building, they could engage in many non-verbal aspects as well: designing the bridge on paper, constructing the bridge with the Popsicle sticks, testing the load capacity of the bridge, and so on. Hispanic participants were also able to use their aesthetic creativity in the "Bridge Building" PBL. None of the constraints dealt with the appearances of the bridges, so the Hispanic students could design theirs with as they saw fit.

No Ethnic Group Indicated (N/A). Participants who did not indicate an ethnic group most mentioned "Bridge Building" as the specific STEM activity in which they used their creativity. They mentioned “3D Printing/Modelling,” “Trebuchet,” and “Multimedia” 1 time each, and they did not mention the other activities. “Bridge Building” clearly appears to be the most creative activity among the STEM summer camp’s participants.

CHAPTER IV:

CONCLUSIONS

Broader Impacts and Intellectual Merit, Article I

Secondary students in general

As previously stated, the worsened visual-spatial skills after taking the course in 3D CAD software may have been due to the many cognitive loads the participants endured while encountering Google Sketchup® for the first time. Not only did the participants need to learn how to design models in the 3D CAD software program, but they also needed to learn how to use the associated tools within the program and to work on an X-Y-Z plane (the latter of which students learn only briefly in their geometry classes) – all in only 2 hours a day, five days per week for two weeks. In addition, prior literature on secondary school students and 3D CAD software indicate that students had worked with the software for at least a month before the analyses began. The results of this present study may have been more optimistic had participants spent adequate time learning the software. However, they still carry intellectual merit: learning new programs—including 3D CAD software—take time, and it may take years of consistent use for Texans to see positive and notable effects.

Secondary students by gender

In terms of 3D CAD software's impact on creativity, the results of this present study were consistent with prior literature for the male participants. The male participants referred to "3D Printing/Modelling" twice as often as the female participants. The male participants also went into more detail in their comments on "3D

Printing/Modelling" than the female participants, suggesting that the male participants felt that the PBL activity stimulated their creativity more so than for the female participants. "3D Printing/Modelling," in addition to aesthetic creativity, involves much creative problem-solving—the type of creativity that males in prior research have highly valued.

In terms of 3D CAD software's impact on visual-spatial skills, however, the results were roughly the same for both male and female participants. The results were also inconsistent with prior research, which indicated a male advantage in this area. This inconsistency could have resulted for numerous reasons. First, the male and female participants could have had less of a gap in visual-spatial ability than typically found in males and females because of the selection process for this particular STEM summer camp. Participants are neither selected based on academic credentials nor their level of representation in STEM. Rather, participants sign up for the camp on a first-come, first-serve basis. The sample, then, consists of secondary school students who may already have a proclivity in STEM. Second, no scholarships are available to cover the cost of each two-week summer camp, so the sample consists largely of secondary students from middle class to upper class backgrounds. The participants also hail not only from Texas, but also from other states (such as Alaska) and other countries (such as Italy and Guatemala). These demographics do not reflect those in Texas public secondary schools, so these results have low external validity in this area. However, they could apply to Texas private secondary schools, which contain more diverse demographics in terms of cultural background and more homogenous demographics in terms of socioeconomic status. Third, both males and females experienced a high cognitive load due to working with 3D CAD software for the first time at this summer camp. Had either the male or female participants had exposure to 3D CAD software beforehand, the results could have been more consistent with the prior literature.

Each of these conclusions have intellectual merit because they could determine how the selection processes for STEM summer camps are changed to include students who (or whose families) may not have an interest or talent in STEM before attending the camp. It could also be changed to exclusively include secondary school students from public schools in Texas. As with the secondary students in general, both male and female participants need more time to learn the dynamics of 3D CAD software before it can help improve their visual-spatial skills.

Broader Impacts and Intellectual Merit, Article II

Secondary students in general

The majority of the findings in this present study are consistent with prior research about creativity in the general population of secondary students, creativity in female secondary students, and creativity in secondary students of various ethnic groups. The results of this research are valid both in terms of construct validity (for the constructs of creative problem-solving and aesthetic creativity) and external validity to Texas secondary students. In summation, the results of this present study could readily be applied to general education Texas secondary students as a whole. If these results achieve the same level of consistency in the field as in this present study, then secondary students may be more likely to take STEM classes or pursue STEM fields that utilize their creative abilities.

Secondary students by gender

When examining the data by gender, the present study indicates expected and consistent results for males, but contradictory results for females. Females tended to comment on the need to use creativity to complete a task without explaining the creative processes involved in that task. This finding is unusual; prior research has suggested that females are more process-oriented than task-oriented. Prior research has also suggested that females tend to value aesthetic creativity over creative problem-solving, and the females in this present study clearly emphasized creative problem-solving over aesthetic creativity. These contradictions, though, do not necessarily invalidate the present study – either in terms of construct validity or external validity. More secondary school females have diverged from creative activities traditionally associated with their gender (for instance, sewing or cosmetics) now than in previous generations. The results of the female participants in the present study could have resulted from a cultural shift between prior research and the time in which the present study occurred. Additionally, the secondary school females who signed up for the camp may have already been interested in STEM or had parents who fostered such interests in STEM. Further research may prove helpful in determining whether this creative problem-solving trend is exclusive to secondary school females already interested in STEM or to secondary school females in Texas as a whole.

Secondary students by ethnic group

When examining the data by ethnic group, the research loses much of its external validity. So few secondary students of non-Caucasian/White ethnic groups attended the STEM summer camp that it remains difficult to generalize these results to Texas secondary students of these same ethnic groups. This is especially problematic for the Black participants in the study, of which there were only 5 in total. Although Black participants made up a very small percentage of the secondary students who attended the camp, they make up a very large percentage of secondary students in Texas. Further research is needed in order to generalize the results of this present study to non-Caucasian Texan secondary students. However, the research still contains its construct validity for creativity for each ethnic group. The majority of the findings are consistent with the prior research and cultural norms of each ethnic group in terms of both aesthetic creativity and creative problem-solving.

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APPENDIX A

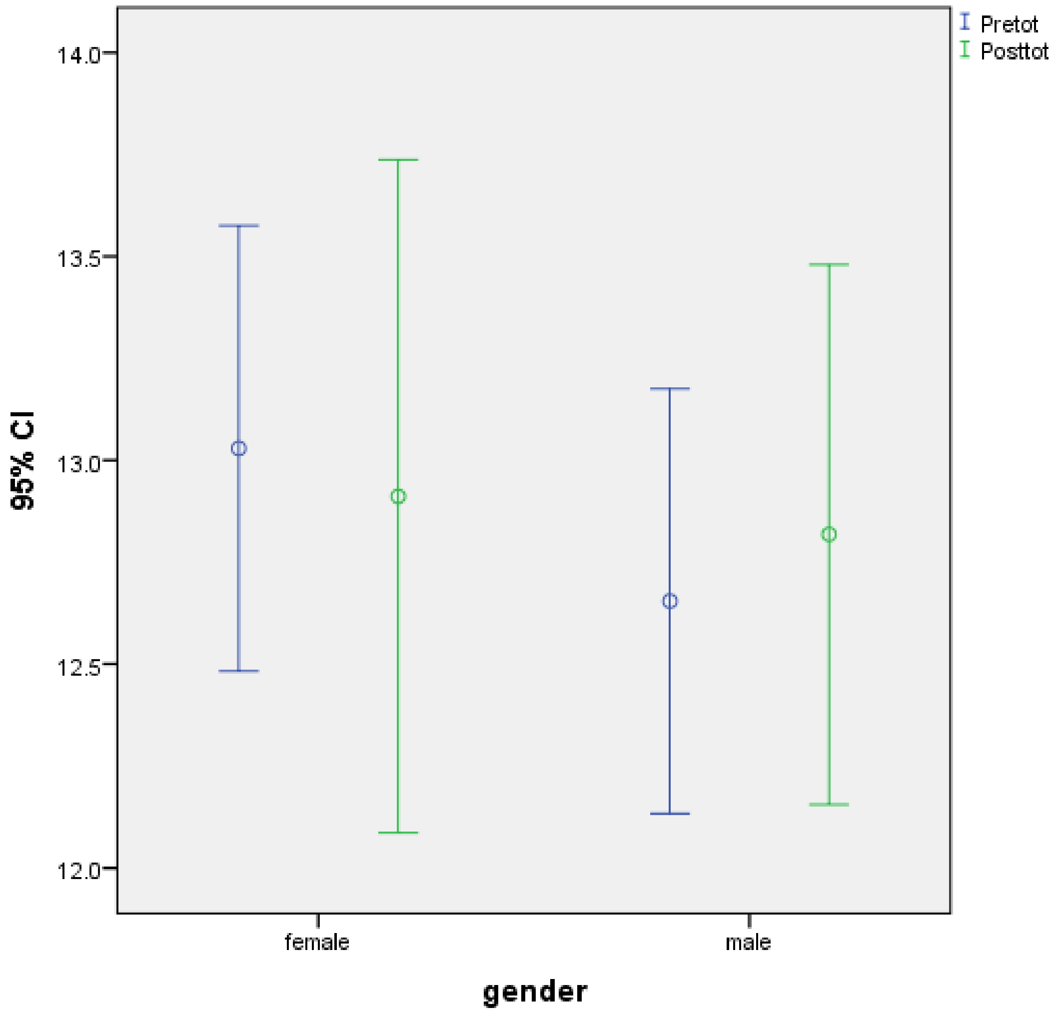
Pre-Camp/Post-Camp Question Pairs

Pre-Camp Question	**Post-Camp Question**
(1) I believe STEM (Science, Technology, Engineering, and Mathematics) courses and careers require a lot of creativity.	(1) I believe STEM (Science, Technology, Engineering, and Mathematics) courses and careers require a lot of creativity.
(2) I believe STEM courses and careers often involve solving problems that require artistic solutions.	(2) I believe STEM courses and careers often involve solving problems that require artistic solutions.
(3) I would be more likely to consider a STEM career if there were applications and problems that required me to use knowledge of the arts (visual art, music, drama, etc.).	(3) I would be more likely to consider a STEM career if there were applications and problems that required me to use knowledge of the arts (visual art, music, drama, etc.).
(4) I would like to have opportunities at the STEM summer camp to use my creativity on one or more projects.	(4)I had an opportunity to use my artistic ability or creativity at the STEM summer camp on one or more projects.
(5)I think I will have an opportunity to use my creativity at the STEM summer camp on one or more projects.	(5)If you had an opportunity to use your creativity, explain how you used creativity in your project(s).

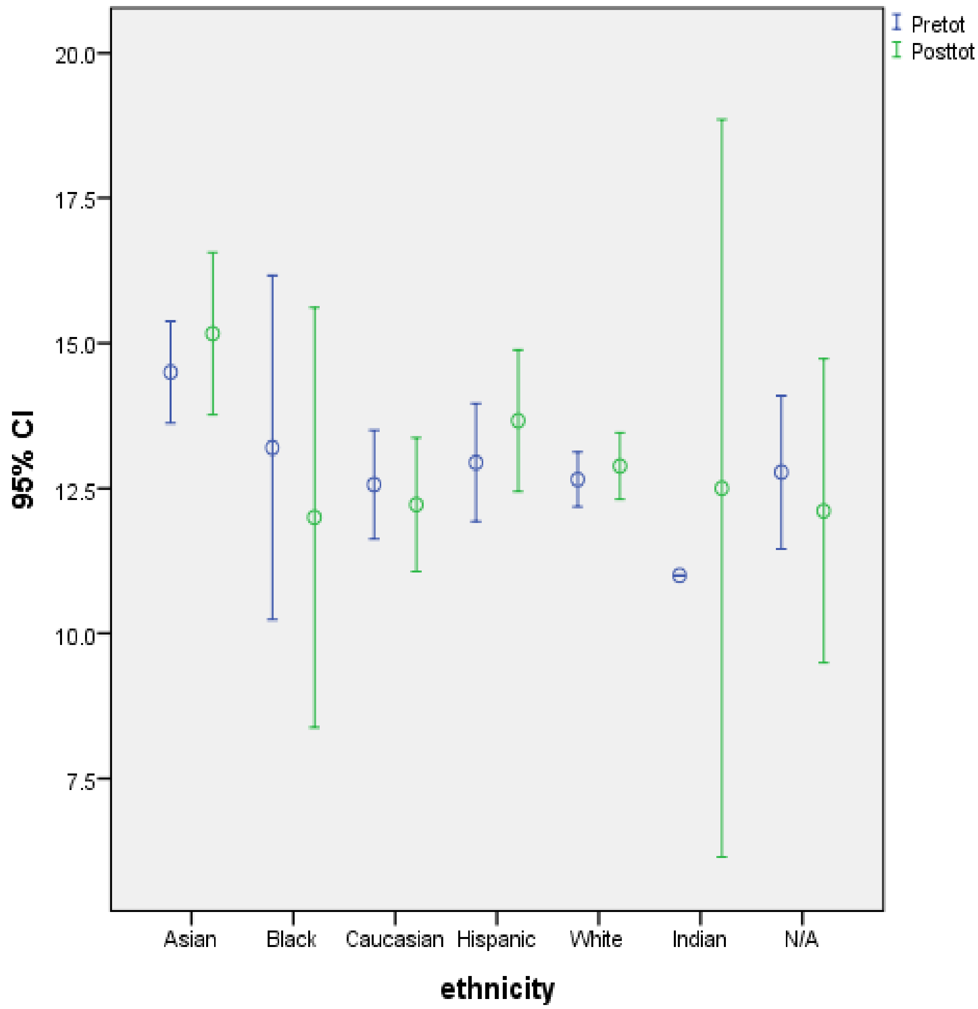
APPENDIX B

Confidence Intervals

95% Confidence Intervals – by Gender (Overall)



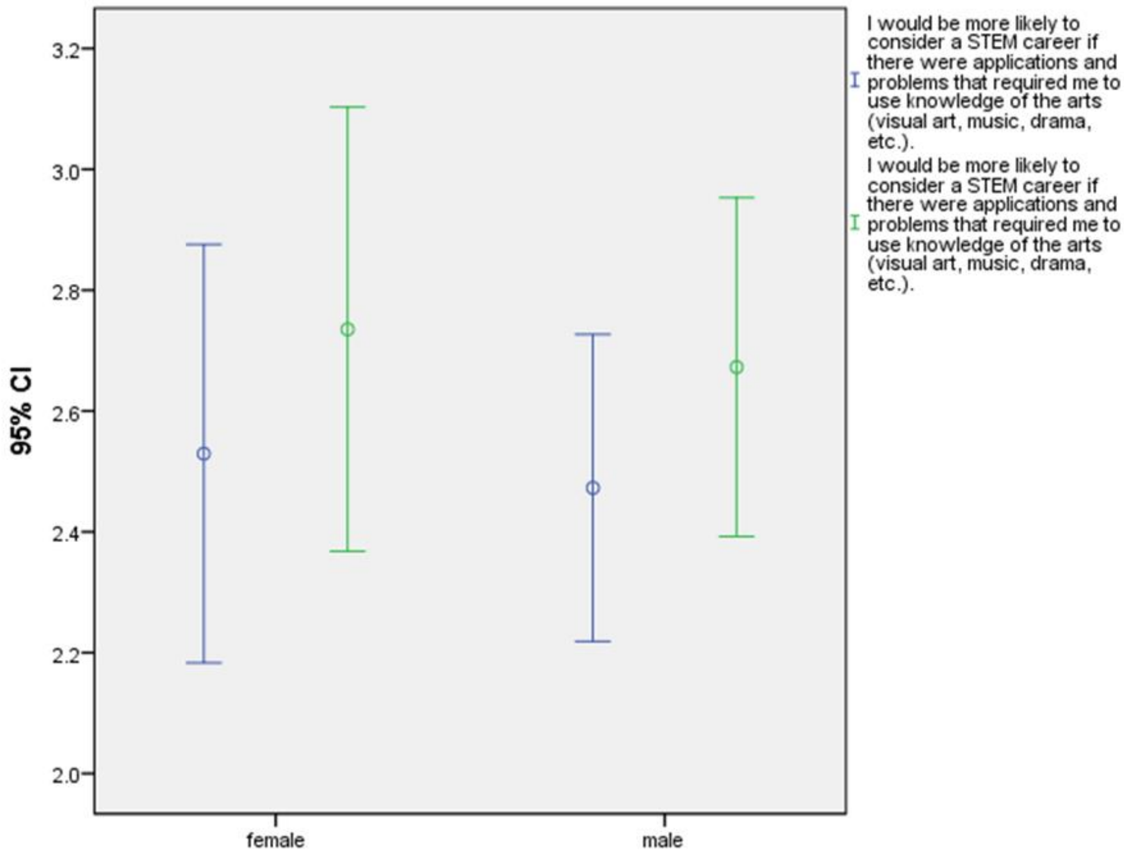
95% Confidence Intervals – by Ethnic Group (Overall)



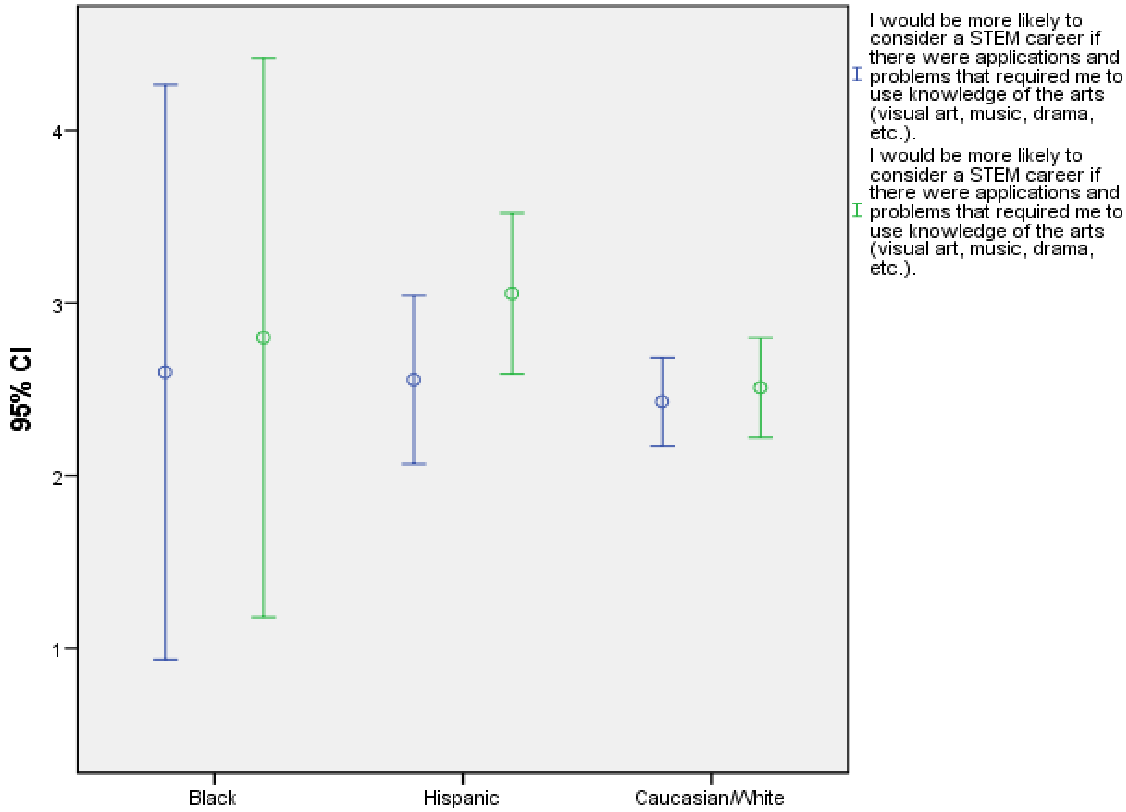
APPENDIX C

Pre-Camp/Post-Camp Question #3 Growth for Underrepresented Students

95% Confidence Interval – Females v. Males

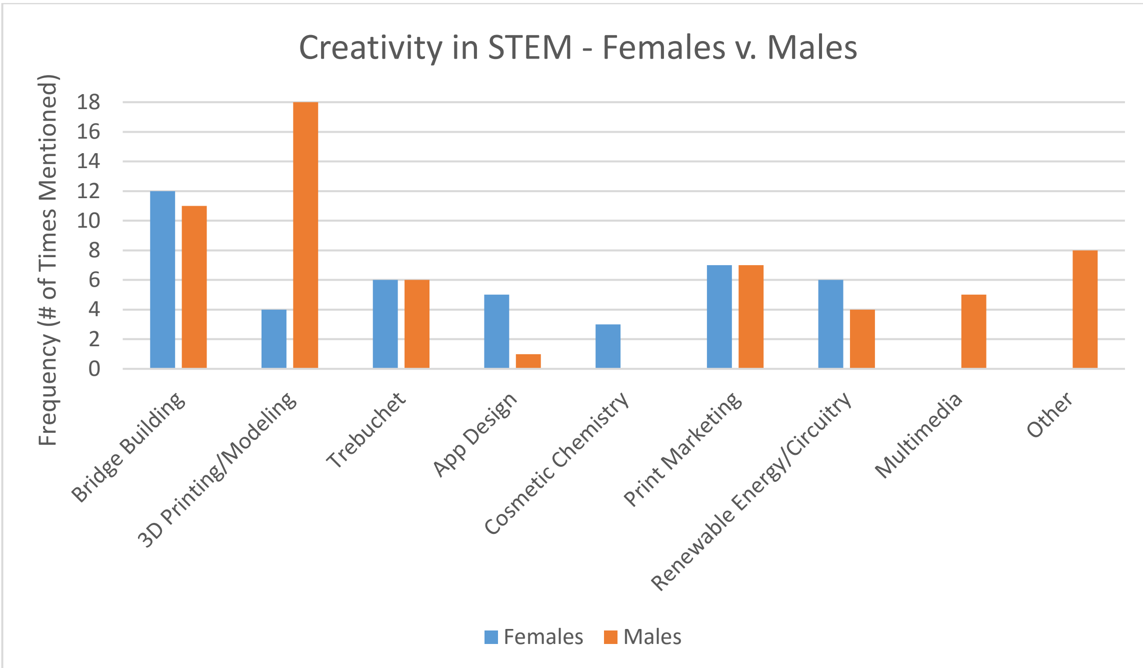


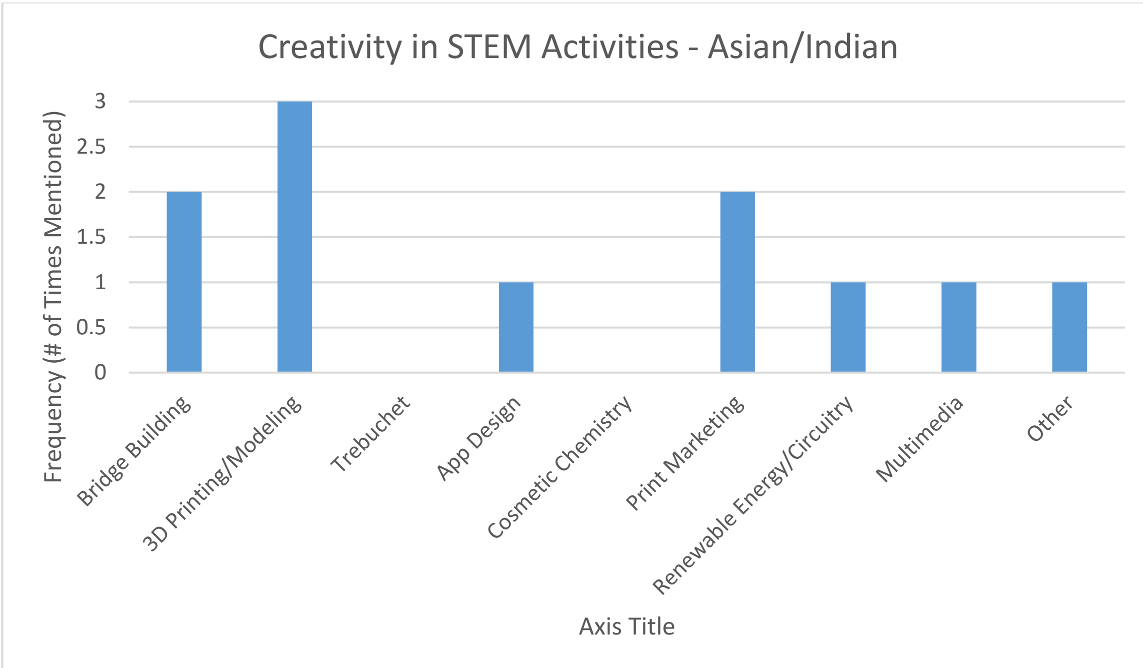
95% Confidence Interval – Blacks v. Hispanics v. Caucasians/Whites



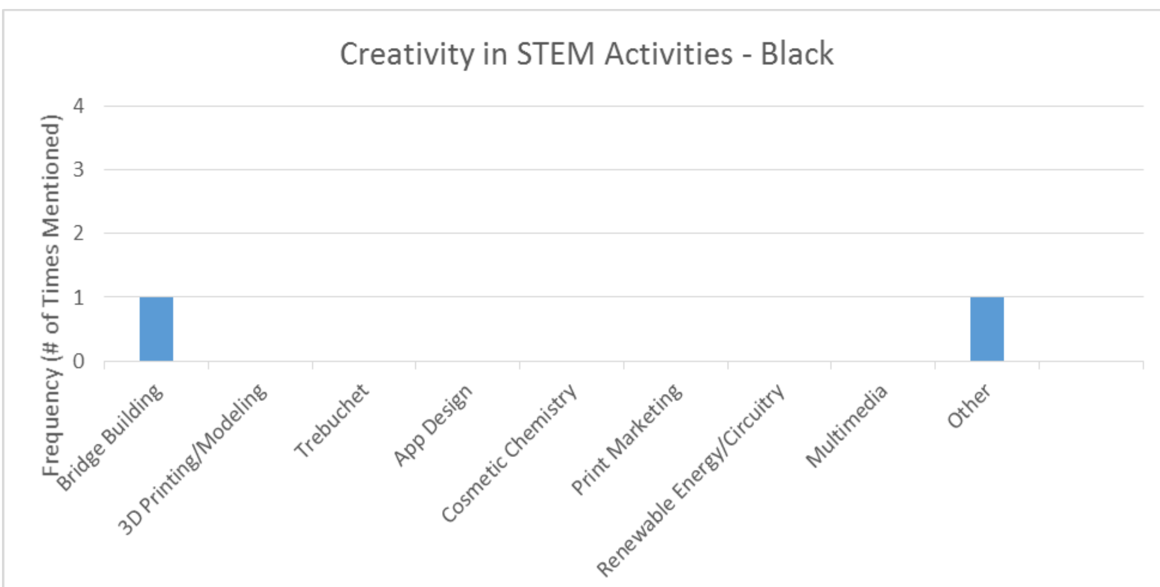
APPENDIX D

Specific Perceptions of Creativity in STEM by Gender and Ethnic Group

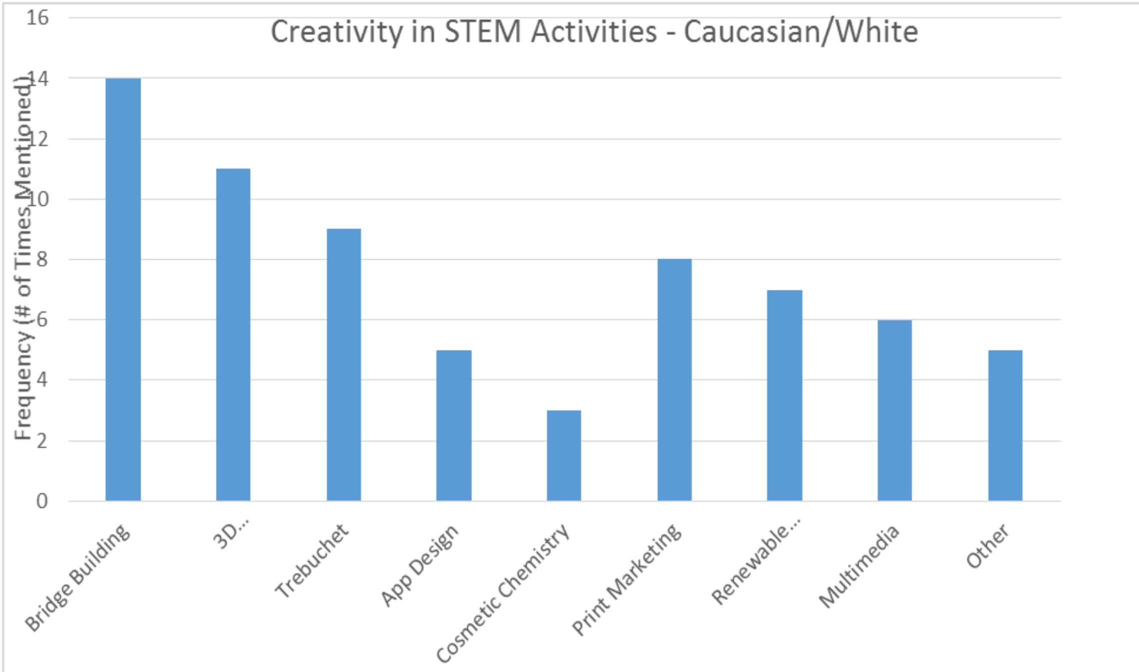


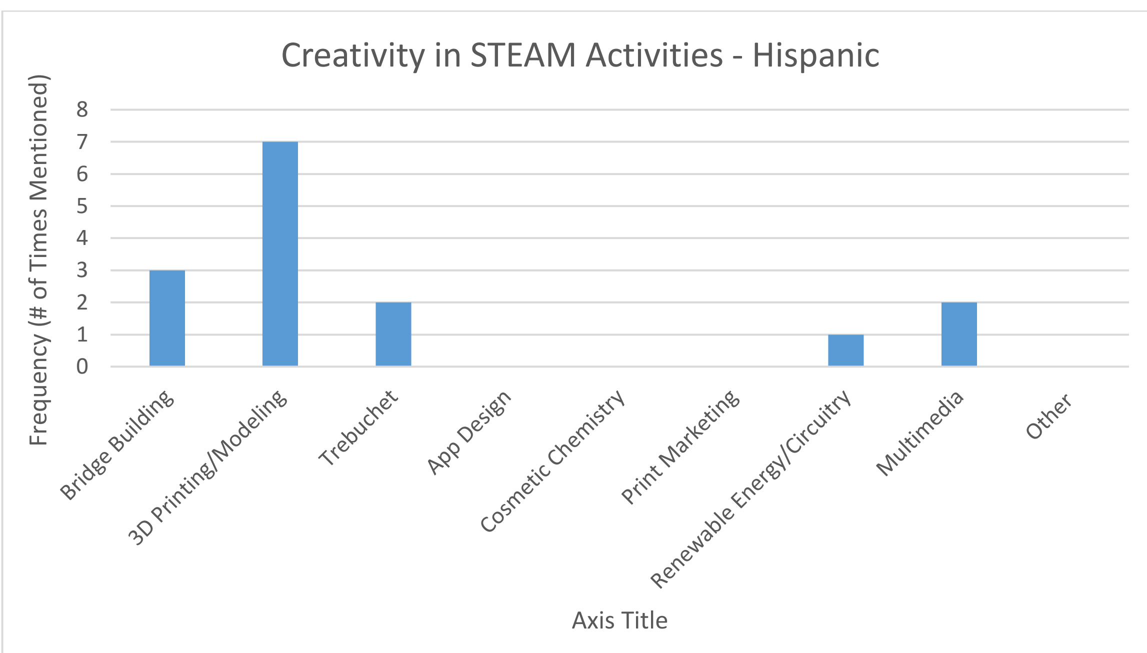


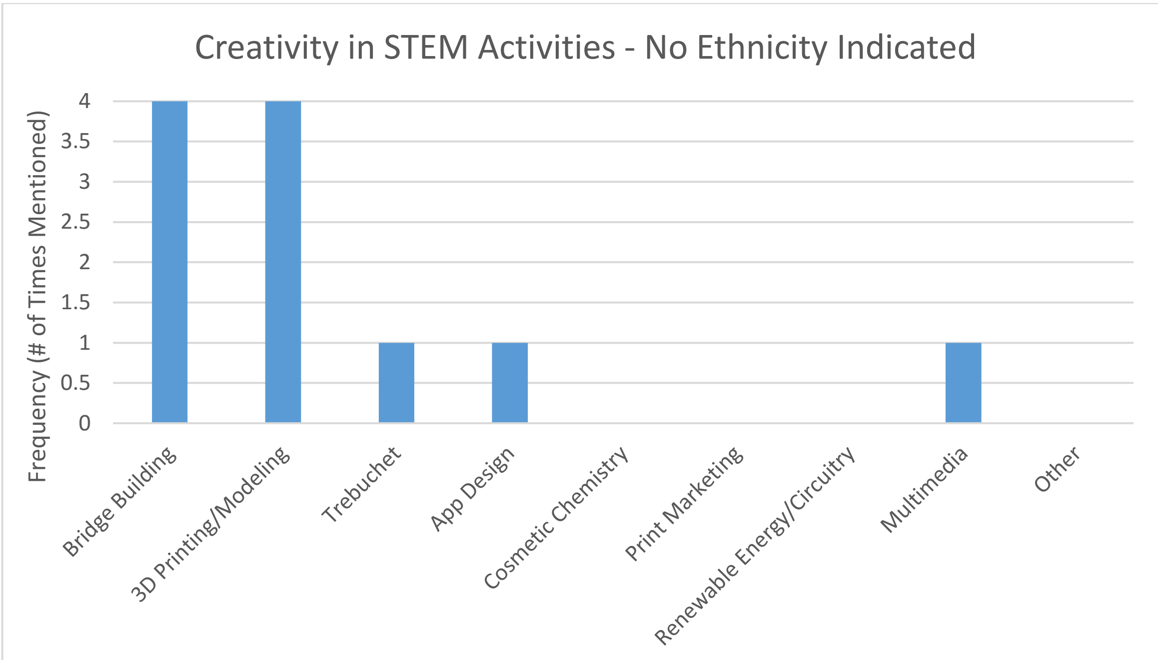
Creativity in STEM Activities - Asian/Indian
Frequency (# of Times Mentioned)
3
2.5
2
1.5
1
0.5
0
Bridge Building
3D Printing/Modeling
Trebuchet
App Design
Cosmetic Chemistry
Print Marketing
Renewable Energy/Circuitry
Multimedia
Other
Axis Title



Creativity in STEM Activities - Black
Frequency (# of Times Mentioned)
4
3
2
1
0
Bridge Building
3D Printing/Modeling
Trebuchet
App Design
Cosmetic Chemistry
Print Marketing
Renewable Energy/Circuitry
Multimedia
Other


Creativity in STEM Activities - Caucasian/White
Frequency (# of Times Mentioned)
16
14
12
10
8
6
4
2
0
Bridge Building
3D...
Trebuchet
App Design
Cosmetic Chemistry
Print Marketing
Renewable...
Multimedia
Other


Creativity in STEAM Activities - Hispanic
Frequency (# of Times Mentioned)
8
7
6
5
4
3
2
1
0
Bridge Building
3D Printing/Modeling
Trebuchet
App Design
Cosmetic Chemistry
Print Marketing
Renewable Energy/Circuitry
Multimedia
Other
Axis Title


Creativity in STEM Activities - No Ethnicity Indicated
Frequency (# of Times Mentioned)
4
3.5
3
2.5
2
1.5
1
0.5
0
Bridge Building
3D Printing/Modeling
Trebuchet
App Design
Cosmetic Chemistry
Print Marketing
Renewable Energy/Circuitry
Multimedia
Other