**Constructivist Learning as Intervention:**

**A Pre-Post Examination of STEM Interest and Self-Efficacy**

## Objectives

With the rapid development in technology, computing and artificial intelligence, the national faces an ever-increasing demand of STEM-related skills in the workforce. Research has highlighted STEM education and career interests as a critical issue in today's society (Roberts et al., 2018; U.S. Bureau of Labor Statistics 2018). Extant literature has identified secondary schools as a crucial time for developing students' knowledge and interest in STEM fields, and also raised the concern that a lack of interest during this time may lead to a lower likelihood of them pursuing STEM careers later in life (Han et al., 2021; Poirier et al., 2009; Roberts et al., 2018). One critical challenge is that there are already clear gender and racial gaps in STEM interest in middle school students (Potvin & Hasni, 2014). The gaps demand effective interventions that help increase secondary school girls' participation in STEM learning because it happens to be the period when students begin to think and make decisions about their future academic and career paths (Wang & Degol, 2017).

The core component of this study was a five-week summer camp that provided Arduino and robotics workshops and group activities to girls in grades 6-11. All activities were structured to ensure that learning took place in a constructivist environment. The camp was designed as a program to increase girls', especially minorities' participation in computer science and engineering. Key elements of camp participants' STEM interest, self-efficacy, and contextual factors were measured both before and after the camp. With the collection and analyses of the survey data, our present study is to examine how constructivist learning environment may impact adolescent girls' STEM learning and interests.

## Background and Conceptual Framework

The shortage of STEM workers in the U.S. is a significant concern for policymakers and industry leaders. According to the national statistics, jobs in computer and information research sciences are projected to grow 23% from 2022 to 2032 (U.S. Bureau of Labor Statistics, 2023). Overall, given the forecasted demand, an estimated increase of undergraduate STEM degrees by 34% is needed. The consistent STEM shortage is worsened by a noted lack of diversity (HR Forecast, 2023). In order to increase the supply of STEM labor force, one important task is to strengthen women's interest and broaden their participation in STEM fields.

In this study, we define STEM interest as an individual's inclination to pursue further education or desire to pursue a career in STEM fields (Potvin & Hasni, 2014). We focus on girls in secondary schools with the knowledge that ages 10-14 is a key transition period in which kids begin to lose interest in STEM and girls are more likely to shun away from math and science subjects (Archer et al., 2012; Kim et al., 2018). Along with STEM interest, another factor we attended to is student self-efficacy. Self-efficacy was introduced by Bandura (1994) as an individual's degree of confidence in one's ability to succeed in a specific task or domain. In this study, we defined STEM self-efficacy as a student' judgment and faith in her ability to complete STEM-related tasks or actions (Rittmayer & Beier, 2008; Shang et al., 2023). Our decision to include this construct is supported by evidence that, first, STEM self-efficacy is found to be a powerful contributor to students' STEM interest and success (e.g., Beier et al, 2019), and second, the certain instructional approaches and well-designed interventions are effective in improving adolescences' STEM efficacy (Beier et al, 2019).

*Constructivist Learning as the Intervention*

The five-week summer camp offered a variety of activities, but what they had in common was carefully structured constructivist learning environment. The core of constructivism learning emphasizes the active role of learners in constructing their own understanding of new information and concepts through participating and reflecting on those experiences (Menekse et al., 2013). The literature shows that students participating programs that offered constructivist learning have more in-depth understanding of STEM concepts and enhanced ability to apply these concepts to real-world problems (e.g., Chang and Brickman, 2018; Pedrosa-de-Jesus et al., 2019).

According to De Kock et al. (2004), the three legs that support a constructivist learning environment include constructive activity, situated contextual activity, and social activity. *Constructive learning activities* occur during meaningful and perplexing problem solving in real-life situations (Menekse et al., 2013). In this study, summer camp participants were arranged in tiered teams to work on projects in the ubiquitous intelligent systems (UIS) system. The constructivist learning took place in hands-on interactive activities that emphasized real-world problem-solving as well as an opportunity to connect STEM concepts with authentic applications. Students were co-mentored by STEM teachers and college seniors who assisted (not led) them with constructing meaning of the learning as well as solving potential conflicts and dilemmas.

*Situated contextual activities* require a setting that encourages self-regulated learning by shifting external control of the learning process (e.g., as emphasized in traditional settings) to student's internal control. For this purpose, our study structured tiered teams as the situated context and used peer interactions to enhance self-regulated learning such as self-assessment, time management, and use of academic resources. The tiered-team design also served well as a structure to facilitate the *social activity* requirement that emphasizes the cooperative dialogical nature of the learning process. Team members were encouraged by the mentors to have arguments, discussions, debates, and idea-sharing as new forms of learning.

*Research Objectives*

Evidence is strong that constructivist learning is an effective instructional approach in STEM education (e.g., Menekse et al., 2013; Xu et al., 2024), but a better understanding is needed about how such learning interventions may impact students' STEM interest and self-efficacy apart from the learning outcome (Drymiotou et al., 2021). In particular, it would contribute to future STEM teaching and learning if we can know in what aspects the constructivist approach impacts STEM interest and self-efficacy. Therefore, this study collected data to answer the following research questions:

1) How did camp participants evaluate their STEM interest and self-efficacy differently before and after participating the summer camp?
2) How did the constructivist learning experience relate to camp participants' changes in STEM interest and self-efficacy?
3) How did the various aspects of constructivist learning experience related to girls' changes in STEM interest and self-efficacy in the summer camp?

## Methods

The target population of our study was female students in middle and high schools (grades 6-11). With an emphasis recruiting from Title 1 schools, especially those with large percentage of underrepresented minority students, we worked with a local school district in the southwest region of the U.S. A program announcement flyer was first publicized in school district's monthly newsletter. Then members of the research team made recruitment trips to middle/high schools and phone calls to principals, counselors, and teachers at the targeted schools in the district. During the on-site visit with MS/HS science teachers, the research team had round-table discussions to learn the expectations of teachers and students.  Qualified teachers were also invited to serve as mentors and asked to encourage students to apply for the summer camp.

Interested students were invited to complete an application form and submit one-paragraph statement of interests, school transcripts, along with a letter of recommendation from the science teacher. A total of 41 students who met the selection criteria were accepted. Before the camp started, the students were contacted by email and asked to complete an online pre-camp survey. At the end of survey, they were asked to volunteer their email addresses and informed that a $10 Amazon e-gift card will be send to their email address if they also complete the post-camp survey and provide a matching email address. Eventually, a sample of 22 participants had valid responses to both pre- and post-camp surveys.

In the summer camp, the first three weeks were organized with the goal of teaching participants computing & engineering knowledge and skills. Participants were free to choose one from the two course modules that were offered in parallel: Computing Basics & Python and Programming and IoT & Robotics. After the first three weeks, they were divided into tiered teams (3-4 girls per team) and worked with their mentors on the UIS engineering projects for the remaining two weeks. It's worth mentioning that, before the summer camp, all mentors went through a one-week training to get familiar with technologies used in the camp as well as mentoring skills that promote students' engagement in self-regulated learning and activities suitable for their cognitive abilities.

*Data collection and Instruments*

We developed the pre- and post-camp online surveys and had them reviewed and finalized by domain experts. The 22 participants provided valid pre- and post-camp responses via Qualtrics.com, which accounted for a 53.6% response rate out of the total 41 participants. Survey items related to the research questions all had 5-point response categories (5 strongly agree, 4 agree, 3 neutral, 2 disagree, and 1 strongly disagree). As summarized in Table 1, the matching questions on the pre- and post-camp surveys formed three subscales measuring STEM interest (5 items, V1), STEM self-efficacy (4 items,V2), and related contextual factors (4 items). On the post-camp survey, additional items (Table 2) were included for two more subscales measuring constructivist learning experience (7 items, V4) and participants' evaluation of the learning outcome (5 items, V3). The **Cronbach's α for the subscales were .760, .809, .393 .814, and .761**, respectively. Note that, first, given the low Cronbach's α of the four items measuring the contextual factors, they were not combined into a subscale. And second, the seven items in the constructivist learning scales were further divided into three dimensions measuring personal experience (V4-1), peer interaction (V4-2), and mentor support (V4-3). Due to small sample size, all significance tests were evaluated with $\alpha = 0.10$.

## Results

In Table 1, detailed information about the matching questions on pre- and post-camp survey is provided, along with the paired t test results. It is intriguing that the participants indicated significant improvement in nine out of the thirteen items despite of limited statistical power due to the extremely small sample size. As subscales, the STEM interest and self-efficacy showed substantial increase of 1.95 and 2.68 standard deviations (Cohen's d values), respectively, with both being statistically significant at $p < .01$. The findings indicate that the camp experiences indeed brought significant improvements to participants' STEM interest and self-efficacy.

In Table 3, the correlations showed that the constructivist learning experience is related to changes in STEM interest at r = .07 and to changes in STEM self-efficacy at r = 0.33; the latter is statistically significant, suggesting that constructivist learning explained about 10.8% of the variance in the observed STEM self-efficacy improvement. Furthermore, the correlations indicate that personal and peer dimensions of the constructivist learning have noticeable relationship with the pre-post changes in STEM self-efficiency (r = .25 and .46, respectively). The findings suggest that constructivist learning has stronger influence on STEM self-efficacy than on STEM interest, and the peer interaction and group learning is the significant contributor to the observed changes.

Due to limitation of the small sample size, more sophisticated statistically analysis is not feasible. Nonetheless, the pre-post improvement in STEM self-efficacy is significantly related to the camp learning outcome (r = 0.39). With the findings in another related study (Xu et al., 2024), our tentative conclusion is that constructivist learning contributes positively to learning outcomes, either directly or indirectly through enhance students' self-efficacy. Finally, it is worth mentioning that girls evaluation of their learning outcome is strongly related (r = 0.91) to their experience in constructivist learning environment, suggesting the importance of effective instructional approach.

## Scientific Significance

Analysis of the survey data provided insight about the importance of instructional approach in STEM education. The unique contribution of the study is the clear evidence that, when given the opportunity to engage in constructivist-grounded active learning and problem-solving, girls' interest and self-efficacy in STEM subjects could be substantially boosted. Both STEM self-efficacy and constructivist learning experience contributed significantly to the camp learning outcomes. Interaction with peer is a critical component of constructivist learning environment that is strongly related to the gain in girls' STEM self-efficacy. Nonetheless, the study needs to be replicated with large samples and more statistical evidence is needed to validate the findings. The results of our current study led to a conclusion that efforts and investment in authentic STEM projects and student-centered instructional pedagogies will pay off in the long run by increasing girls' engagement and self-efficacy in STEM.

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Table 1.

*Comparison of pre- and post-camp survey responses.*

| | SD | D | N | A | SA | Mean | Std. Dev. | Paired t test |
|---|---|---|---|---|---|---|---|---|
| **STEM Interest** | | | | | | | | ***t* =2.63, *p* = .008** |
| I am genuinely interested in subjects in | | 1 | 1 | 9 | 11 | 4.36 | .790 | ***t* =3.13** |
| STEM areas. | | | 1 | 5 | 16 | 4.68 | .568 | ***p* = .005** |
| It is fun to solve math or science problems. | | | 3 | 12 | 7 | 4.18 | .664 | *t =0.326* |
| | | | 4 | 9 | 9 | 4.23 | .752 | *p* = .374 |
| I plan to take more STEM courses in the | | 1 | 3 | 11 | 7 | 4.09 | .811 | ***t* =2.16** |
| future. | | | 4 | 4 | 14 | 4.45 | .800 | ***p* = .021** |
| I am interested in pursuing a college degree | | | 6 | 8 | 8 | 4.09 | .811 | *t =-0.37* |
| in STEM-related majors. | | | 6 | 6 | 9 | 4.05 | .950 | *p* = .357 |
| I can see myself as a computer scientist or | 1 | | 8 | 7 | 6 | 3.77 | 1.020 | ***t* =1.62** |
| engineer in the future. | | 1 | 4 | 7 | 10 | 4.18 | .907 | ***p* = .060** |
| **STEM Self-efficacy** | | | | | | | | ***t* =3.26, *p* = .002** |
| I am good at using scientific principles to | 1 | 1 | 8 | 8 | 4 | 3.59 | 1.008 | *t =.93* |
| explain phenomenon in daily life. | | 1 | 4 | 15 | 2 | 3.82 | .664 | *p* = .183 |
| (pre) I expect to do very well in the upcoming summer camp. / | | 1 | 7 | 11 | 3 | 3.73 | .767 | ***t* =4.23** |
| (post) I felt satisfied with what I learned at the summer camp. | | | 1 | 8 | 13 | 4.55 | .596 | ***p* < .001** |
| (pre) I am confident that I will be able overcome challenges in learning STEM-related subjects. | | | 4 | 12 | 6 | 4.09 | .684 | ***t* =1.78** |
| (post) I was able overcome challenges in learning STEM-related subjects in the camp. | | | 3 | 7 | 12 | 4.41 | .734 | ***p* = .045** |
| Compared to my peers, I think I know a | 1 | 3 | 12 | 4 | 2 | 3.14 | .941 | ***t* =2.43** |
| great deal about STEM subjects. | 2 | | 8 | 6 | 6 | 3.64 | 1.177 | ***p* = .012** |
| **Contextual** | | | | | | | | ***t* =2.67, *p* = .007** |
| I enjoy collaborating with others when | 1 | | 6 | 13 | 2 | 3.68 | .839 | ***t* =2.45** |
| solving STEM-related problems. | 1 | 1 | 2 | 4 | 14 | 4.32 | 1.129 | ***p* = .023** |
| Support from my peers is important if I | 1 | | 8 | 11 | 2 | 3.59 | .854 | ***t* =1.52** |
| choose STEM disciplines as a college major. | | 2 | 2 | 12 | 6 | 4.00 | .873 | ***p* = .071** |
| My family will support me if I decide to | | | 1 | 9 | 12 | 4.50 | .598 | ***t* =1.82** |
| choose STEM disciplines as my college major. | | | 2 | 1 | 19 | 4.77 | .612 | ***p* = .041** |
| It is unlikely for me to choose a college | 12 | 8 | 2 | | | 1.55 | .671 | *t =0.826* |
| major in STEM because they are not for girls. | 13 | 3 | 6 | | | 1.68 | .894 | *p* = .209 |

Table 2.

*Post-camp survey questions organized by subscales, and descriptive statistics.*

| **Evaluation of learning outcomes (Cronbach's alpha = .814)** | Mean | Std. dev. |
|---|---|---|
| Activities in the summer camp helped me understand how to apply knowledge to solve real problems. | 4.32 | .716 |
| The projects gave me a better understanding of the importance of STEM fields. | 4.32 | .780 |
| The STEM projects in the camp offered great examples of how subjects taught in school STEM courses can be utilized in real life. | 4.50 | .673 |
| The summer camp allowed me to examine issues related to computing and engineering from multiple perspectives. | 4.55 | .739 |
| The summer camp contained a variety of learning activities that increase my STEM knowledge and skills. | 4.68 | .568 |
| **Constructive learning (Cronbach's alpha = .761)** | | |
| I was given sufficient opportunities to explore different ideas and perspectives in the summer camp. | 4.27 | .631 |
| I was given sufficient opportunities to share my own experiences with others in the camp. | 4.18 | .733 |
| I enjoyed the collaboration among my team members during the summer camp. | 4.27 | .985 |
| Peers in my tiered team supported each other for successfully completion of the project. | 4.36 | 1.002 |
| My mentors were good at keeping team members challenged with various tasks. | 4.09 | 1.065 |
| My mentors encouraged critical thinking through discussions and debates. | 4.27 | .767 |
| My mentors provided helpful feedback for me to perform better in camp activities. | 4.45 | .739 |

Table 3

*Correlations and coefficients of determinations between variables.*

| | V1 | V2 | V3 | V4 | V4-1 | V4-2 | V4-3 | Mean | Std Dev |
|---|---|---|---|---|---|---|---|---|---|
| V1: Pre-Post difference in STEM interest | - | 0.202 | 0.011 | 0.005 | 0.014 | 0.007 | 0.000 | 1.09 | 1.95 |
| V2: Pre-Post difference in STEM self-efficacy | **0.45** | - | **0.152** | **0.108** | 0.060 | **0.214** | 0.004 | 1.86 | 2.68 |
| V3: Camp Learning outcome | 0.10 | **0.39** | - | | | | | 22.36 | 2.65 |
| V4: Constructivist learning experience | 0.07 | **0.33** | 0.**91** | - | | | | 29.91 | 4.05 |
| V4-1: Constructivist learning: Self | 0.12 | 0.25 | **0.63** | **0.76** | - | | | 8.45 | 1.26 |
| V4-2: Constructivist learning: Peer | 0.09 | **0.46** | **0.76** | **0.80** | **0.56** | **-** | | 8.64 | 1.92 |
| V4-3: Constructivist learning: Mentor | -0.01 | 0.07 | **0.70** | **0.76** | 0.37 | 0.30 | - | 12.82 | 2.04 |

*Notes:*

*1*. Numbers above the diagonal line are coefficients of determination
2. Numbers in bold are significant at .05 level.