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Exploring Elementary Student and Teacher Perceptions of STEM and CS Abilities

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ABSTRACT

Curriculum, legislation, and standards across the nation are quickly evolving to incorporate computer science and computational thinking concepts into K-12 classrooms. For example, many states have passed legislation requiring computer science to be included in every school's curriculum. Most states, however, report high shortages of qualified computer science teachers, meaning, teachers without extensive training will be required to integrate these concepts into their classrooms—a daunting task for most teachers without the necessary background and experiences. This paper reports the impacts of a thirteen-week intervention in a local elementary school designed to introduce computational thinking skills to 4th and 5th grade students. This intervention involved the first two authors working with a teacher and her students to introduce a project-based activity into the traditional curriculum. As students worked to design, build, and automate a model clubhouse, they incorporated foundational construction concepts as well as computational thinking skills. Our findings shed light on the potential for such a project to influence student and teacher's perceptions of related fields, and abilities, and student's perceptions of related professions.

Keywords: Computer science education, STEM education, computational thinking, elementary education

Technological advancements have given rise to pressure on districts, schools, and teachers to incorporate Science, Technology, Engineering, and Mathematics (STEM) and Computer Science (CS) into their classrooms (Nager & Atkinson, 2016). While the effects of this integration have generally been lauded (Martín-Páez et al., 2019) and demonstrated positive outcomes for students (Stohlman et al., 2012), teachers are not always comfortable integrating these concepts into their classrooms (Margot & Kettler, 2019). This can be especially true when it comes to CS concepts – sometimes referred to as computational thinking (CT; Barr & Stephenson 2011) skills when taught as broader ideas outside of programming language specifics (Yadav et al., 2016). While CT and CS are multi-faceted fields that include a variety of concepts, practices, and perspectives, this effort sought to explore the impact of exploratory, and introductory, STEM/CS activities in an elementary school classroom. Understanding how to best assist teachers and students in learning these STEM/CS/CT skills is vital if additional efforts in this vein are to be successful – especially when it comes to younger grade levels where teachers report the least confidence in adding these concepts to their classrooms (Ketelhut et al., 2020).

Project-based Learning & STEM Education

STEM education is an effort to integrate the subjects of Science, Technology, Engineering and Mathematics so that the traditional barriers between these subjects are removed (Kennedy & Odell, 2014); in this way the focus becomes the applied process of designing solutions to contextual problems using tools and technologies. Kennedy, & Odell (2014) suggest the interdisciplinary nature of STEM requires pedagogical approaches that differ from the traditional approaches used within schools, stating that "STEM Educators must use problem-based and project-based learning with a set of specific learning outcomes to support student learning (p. 256)."

In this context, project-based learning (PBL) can be used as a means of providing an authentic experience for students through scaffolded learning and connections within science, technology, engineering, and mathematics. This process is described by Capraro, Capraro, & Morgan (2013, p. 2), who argue that an "advantage to integrating STEM and PBL is the inclusion of authentic tasks (often the construction of an artifact) and task-specific vocabulary." They further go on to define STEM PBL as "an ill-defined task within a well-defined outcome situated with a contextually rich task requiring students to solve several problems which when considered in their entirety showcase student mastery of several concepts of various STEM subjects" (Capraro et al., 2013, p. 2). In this light, PBL extends beyond completing traditional summative assessment projects at the end of learning units; rather, PBL is seen as shifting learning so that students explore, learn, receive formative feedback and complete summative assessments all while pursuing real-world solutions in the form of long-term projects (Markham, 2011). The freedom and challenge presented to students leads to higher levels of engagement in course content, as well as engagement with ethical, aesthetic, and collaborative concerns (Kokotsaki et al., 2016). These projects can also allow students to focus on problem solving and to employ critical thinking skills (Markham, 2011).

Computer Science Education & the Micro:bit

As Computer Science (CS) grows in its global influence (Bureau of Labor Statistics, 2020), an emphasis on teaching CS principles has grown at all levels of education (Hambrusch, 2018). The history of CS begins with computers created by industry labs like IBM; in these settings, CS training was first provided to students through graduate programs (Wood et al., n.d.) in preparation for industry jobs. However, as the field of computing grew, CS education (CSE) shifted towards an emphasis on broader computing principles which were then added to undergraduate university programs (Wood et al., n.d.) before eventually extending down into high school classrooms (Turner, 1985). In recent years, government and institutional expectations of CS offerings in schools have greatly increased (Code.org Advocacy Coalition, 2019) and CSE has found its way further down into K-12 classrooms (Google Inc. & Gallup Inc., 2016).

The increased emphasis on CSE has been followed by an increase in the adoption of CS standards across many states; for example, a 2019 report noted that 34 states have formal CS standards, and five more have standards currently in progress (Code.org Advocacy Coalition,

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2019). This number represents over a 550% increase in states that have CS standards from 2017 (Code.org Advocacy Coalition, 2019). In light of these recently developed requirements, the availability of both physical and curriculum resources have become increasingly important (Prottsman, 2014). For example, while the state of Indiana has had K12 CS Standards since 2016, Indiana recently passed legislation SEA 172 (Office of Teaching and Learning, 2018) which requires every school to include CS in its K12 curriculum by 2021. This integration is intended to address standards with benchmarks such as: creating software to control systems (K-2.DI.3), using algorithmic problem solving to design a solution to a problem (3-5.DI.1), and implementing a solution using a block-based visual programming language (3-5.PA.3)(Office of Teaching and Learning, 2018).

However, while there is an increased push for organized implementation of CS activities (Prottsman, 2014) and availability for targeted elementary schools (Waterman et al., 2020), there is still limited access to resources and implementation of training for elementary teachers. Further, many educators are being asked to implement CSE with limited or no formal training, resulting in gaps in content knowledge and understanding of the complexities of the field (Blikstein, 2018). These gaps are especially prevalent in line with gender differences in participation, perseverance, and employment in CSE and CS fields (Charlesworth & Banaji, 2019). For example, only 19% of AP Computer Science test takers are female and even less (18%) persevere through college to earn a degree in computer and information sciences (NCWIT, 2012). While a variety of research efforts (Abbate, 2017; Vitores & Gil-Juaarez, 2015; Bennett, 2011) into understanding, and potentially levelling this gap have been implemented, little progress has been made (Charlesworth & Banaji, 2019).

In tandem with the standards and benchmarks that teachers are required to implement in classrooms, there are a myriad of technology devices, software programs, websites, and other mediums that can be used to facilitate CSE (e.g., Arduino, RaspberryPi, Scratch, and AppInventor). The abundance of options, mediums, and processes often result in frustration for teachers (Sentance & Csizmadia, 2017). However, one technology device, the *Micro:bit (microbit.org)*, has been increasingly adopted at the elementary level with high levels of success (Schmidt, 2016). The *Micro:bit,* is a hardware computing platform that includes a processor as well as input and output devices. *Micro:bit* integrates with several program editors including one block-based visual programming platform called Blockly (Schmidt, 2016) and relies on a web-based interface for programming and downloading code. Developed in the United Kingdom in 2016, the *Micro:bit* originated with the intent of assisting students to receive an easy first introduction to physical computing with limited prior experience (Teiermayer, 2019). Current research regarding the effectiveness of the *Micro:bit* itself, and block-based programming in education more largely, is inconclusive but the use of these learning tools is growing in popularity (Brown et al., 2016).

The intervention described in this paper emphasizes student exposure to event listeners, conditionals, and loops as part of the larger block-based programming options available at makecode.org for the *Micro:bit*. Although learning these techniques in a block-based environment includes simplifications of loops and Boolean elements that may result in student misconceptions (Grover & Basu, 2017), block-based programming has been shown to improve students' future capacity to learn more advanced programming skills, including increased speed of learning new concepts and higher cognitive levels of understanding (Armoni et al., 2015).

Research Objective

Legislation, mandates, and other educational reform efforts (e.g., Indiana Senate Bill 172 requires that every public school, beginning July 1, 2021, include computer science in the school's curriculum for students in grades K-12) have increasingly focused on integrating CSE at younger and younger grade levels (Code.org Advocacy Coalition, 2020). However, the comfort, abilities, and readiness of teachers to implement such changes to their curriculum is in doubt (Sentance & Csizmadia, 2017). Therefore, in an effort to 1) assist teachers with legislative mandates by modeling a CS-focused unit, and 2) understand the implications of such an intervention, we determined to test and study the impacts of an in-class PBL unit with local elementary school students. Specifically, given the research findings into wide gender disparities in CSE, we were interested in the implications of such a unit broadly on perceptions among students, as well as more narrowly in terms of gender. This unit engaged students in applying acquired knowledge as they designed, built, and automated a model clubhouse. Our research aimed to explore ideas around teaching CS principles, engineering and technical concepts, and whether an educational intervention might influence teacher and students' perceptions of STEM and CS. The guiding research questions for our investigation were:

1. What are the impacts, if any, of the SMART Clubhouse unit on teacher and student perceptions of STEM and CS?
2. What insight does this activity provide into students' perceptions of, and abilities related to CS and related careers?
3. What are the impacts, if any, of the SMART Clubhouse unit on student perceptions of gender capabilities in STEM and CS?

Methods

This research intervention took place during one semester of school in a public elementary school (grades K-5; ages 5-12) serving approximately 600 students in the state of Indiana. The classroom for this study was a high ability, multi-age classroom, composed of 24 fourth and fifth grade students (10 females, and 14 males, ages 9-11). The teacher was recommended for participation in the study by the school principal, based on expressed interest in including more STEM and CS content in the classroom. Following consent from the teacher to participate, all students enrolled in the multi-age class were invited to participate, and both consent from parents and assent from the students was obtained. All students (n = 24 students) enrolled in the class were included in the outlined intervention, but the data presented in this paper includes information only from those with both consent and assent obtained (n= 22 students, 1 teacher).

The thirteen-week intervention, referred to here as the *SMART Clubhouse Unit*, consisted of pre-questionnaires, clubhouse design, building, automation activities, post-questionnaires, and semi-structured interviews with randomly selected students and the classroom teacher. The details of the intervention are described in further detail below.

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Procedure

The research team prepared the necessary Institutional Review Board (IRB) forms and developed all other required materials prior to implementing the intervention within the classroom. Specifically, instructional materials —including worksheets and a booklet (for students), PowerPoints, and physical design and build supplies for each student—were prepared for each of the topics covered (including setup, architecture/construction, computational thinking and automation, manufacturing, and finishing touches). Additionally, the measurement instruments were developed during this time based on the Student Attitudes toward STEM survey (S-STEM; Friday Institute for Educational Innovation, 2012). The S-STEM survey, which collects data pertaining to students' thoughts and feelings regarding STEM subjects and related careers, was modified for this research to include a section related to computational thinking in line with the research objectives (see Appendix A). Further, minor edits were made to questions to improve clarity and comprehension for elementary students (e.g., the existing question "I can handle most subjects well, but I cannot do a good job with math." was changed to "I can understand most subjects easily, but math is difficult for me."). Lastly, the researchers added two questions to each section of the S-STEM survey specifically related to gender (e.g., "I believe that boys can be good at computational thinking") based on the research into the gender gap in CSE (Charlesworth & Banaji, 2019). These questions also aligned well discussions with the classroom teacher where it became evident that perceptions of competence across genders was an area of potential interest to the teacher. The final administered questionnaire (see Appendix A) consisted of 45 questions regarding student's perceived abilities in, and perceptions of STEM, CS, and related career fields.

Intervention

The first day of the intervention was used to introduce the teacher and students to the project, including its purpose and an overview of activities. The research team distributed supply kits to students that would be used for the duration of the intervention and showed the teacher and students a fully automated clubhouse (created prior to the intervention by one of the researchers) to give them a better sense of the scope of the project. Additionally, this time provided the researchers with a chance to obtain assent from students and send consent forms home to parents.

On the second day of the intervention, consent forms were collected and the modified S-STEM Survey (Appendix, A; based on Friday Institute for Educational Innovation, 2012) was administered to all students. The directions and example questions were read to students prior to taking the questionnaire to ensure that students were familiar with the five-point Likert used within the questionnaire. Each page of the questionnaire provided students with a paragraph outlining specific concept definitions and information related to possible careers within the field (see Figure 1). Students were asked to respond to the 45 questions independently but were allowed to ask questions if they were unfamiliar with any of the terms or had questions regarding the questionnaire. In order to protect the identity of students throughout the intervention, the teacher created unique identifiers for each student which were used on all student questionnaires, worksheets, clubhouses, interviews, and consent and assent forms. These unique identifiers were known only to the teacher and were used throughout the intervention.

Computational Thinking

Please read this paragraph before you answer the questions.

Computational Thinking *is a problem-solving process that is used in many areas such as developing computer applications. Those who work with computational thinking may program a device to perform a function, develop a program to play a video game, or automate (make something happen without human help) a process.*

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
33. I can break down large ideas into smaller parts	○	○	○	○	○
34. I like to find patterns and trends in things.	○	○	○	○	○
35. When I observe a pattern I can identify the rules of the pattern.	○	○	○	○	○
36. I am curious about how computers, machines, and electronic devices work.	○	○	○	○	○
37. I feel good when I design or make something that uses technology.	○	○	○	○	○
38. I can develop instructions for solving a problem or completing a task.	○	○	○	○	○
39. I can use models and simulations to see how things work.	○	○	○	○	○
40. I like to collect data to help me make a decision.	○	○	○	○	○
41. I believe that girls can be good at computational thinking	○	○	○	○	○
42. I can program something to perform a task.	○	○	○	○	○
43. I believe that boys can be good at computational thinking	○	○	○	○	○
44. I can visualize collected data to better understand something.	○	○	○	○	○
45. I believe I can be successful in computational thinking.	○	○	○	○	○

Figure 1. Sample page from the Measurement Instrument

Following the completion of the initial questionnaires, the research team visited the classroom for a total of 21, 90-minute class periods over the course of thirteen weeks. The intervention consisted of instruction and activities related to the topics mentioned previously. An outline of the schedule is included in Table 1.

In addition to the questionnaires and outcomes from the daily activities (e.g., worksheets), the student researcher kept field notes for each visit. These notes related to class discussions, progress, observations, and insights shared by the students related to the intervention. These field notes were saved for use in conjunction with the survey data analysis as a means of triangulating findings with both the quantitative data from the questionnaires and the qualitative data collected from students through the semi-structured interviews.

Finally, following the thirteen weeks of classroom activities, all students once again completed the modified S-STEM questionnaire. All previously used protocols were again used during the administration of the modified S-STEM Survey and the unique identifiers for each student were used to match pre- and post-questionnaires. Following completion, all student data points were matched, and the collected data were conditioned for analysis. This process involved coding responses numerically (i.e., “Strongly Disagree” responses were coded as “-2,” “Disagree” responses were coded as “-1,” “Neither Agree nor Disagree” responses were coded as “0,” “Agree” responses were coded as “1,” and “Strongly Agree” responses were coded as “2”) and removing missing data points. This conditioning facilitated analysis of data by allowing the researcher to investigate any changes in students’ responses (i.e., from disagree [-1] to agree [1] etc.) from the pre- to post-questionnaires.

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Table 1.
Classroom schedule for the intervention

Topic	Day	Class Schedule
Introduction/ Setup	1	• Introduce project, overview/ purpose, show clubhouse, • Consent/assent forms
	2	• Pre-Questionnaires, Smart Homes (architecture, trends, needs) • Brainstorming Ideas- what could my clubhouse look like?
Architecture / Construction	3	• What's the process of creating a building from start to finish? • What are blueprints? • Scaling activity, Floor Plans
	4	• Proper Wall framing guidelines- why do we have building codes? • Framing basics (wall, window, door), Wall Framing stations
	5	• Model supplies, scale, plans • Begin framing base
	6	• Wall Workday
	7	• Wall Workday
	8	• Wall with Door Workday
	9	• Wall with Window Workday
	10	• Finish building & Erect Structure • Wall framework assessment
Computer Programming & Automation	11	• Programming basics • Robot cup stacking activity • Directions Packet o conditional statements (if/then)
	12	• Components (physical) o LEDs, Motors, Wires, Sensors & circuits
	13	• Micro:bit basics o Start/Wait, Loops, Conditionals (if/then), High/low (on/off), input/output & variables
	14	• Programming Doorbell o Touch sensor o Buzzer/Tone
	15	• Programming LED Light o Light sensor o LED
	16	• Programming Thermostat and Fan o OLED screen o Fan o Temperature sensor
	17	• Introduction to Nesting
	18	• Programming Workday
	19	• Programming Workday
Manufacturing	20	• Manufacturing processes, materials, & automation • Home manufacturing: Siding, brick, finishing • Workday Thingiverse / TinkerCAD
Wrap-Up	21	• Review project- what did we learn? • Post Questionnaires • Interviews

Interviews

At the conclusion of the study the participating classroom teacher was interviewed in line with our stated research objective of understanding the impact of this intervention on teacher's perceptions of areas such as STEM and CS. This interview followed protocols and procedures outlined for interviews by Berg (2009) and was guided by a list of questions (see Figure 2), with follow-up questions to explore comments made by the teacher during the interview. The semi-structured interview was conducted at the school and lasted approximately 20 minutes.

1) What did you like/ about the intervention?
2) What observations did you make?
    - What did students learn?
    - What was difficult for the students?
    - What was difficult for you?
    - What surprised you?
3) Would you ever do this project again?
    - Would you do something similar?
    - Why or why not?
    - What are your takeaways?
4) What STEM concepts do you feel the students learned?
    - How did this activity help with these concepts?
    - Did the activity help tie into what you were doing in your class? How?
5) What is your confidence level in this content?
    - What is your confidence level in this activity?
    - What is your confidence level in your ability to do this activity/ similar activity?

Figure 2. *Semi-structured interview questions for the teacher*

Additionally, individual interviews were conducted using semi-structured interview procedures as outlined by Berg (2009) with nine randomly selected students. These randomly selected students were notified of the interviews and additional assent (student) and consent (parental) was obtained prior to participating in the interviews. Students were asked several open-ended questions (see Figure 3) in an effort to better understand their experience related to the intervention and determine their perceptions of STEM, CS and related topics (e.g., construction). Clarifying questions were also asked by the research team to further explore information surrounding the students' experiences. Each interview was conducted at the school and averaged approximately 6 minutes. Students were informed that their interviews would be audio recorded and later transcribed, but no identifying information would be used in the analysis (students were instructed that personal information [e.g., name] was not to be shared during the interview).

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1) Tell me about your experience with the SMART clubhouses project
2) What did you like, dislike, etc.?
3) What was hard, easy, fun, exciting, challenging?
4) What did you learn about **Science** while working on this project?
5) What did you learn about **Math** while working on this project?
6) What did you learn about **Technology** while working on this project?
7) What did you learn about **Engineering** while working on this project?
8) What did you learn about **Computer Science** while working on this project?
9) What did you learn about **Construction** while working on this project?
10) Would you consider a career in any of these fields after an experience like this?
11) Is there anything else you would like to share with me about this experience with the Smart Clubhouses?

Figure 3. *Semi-structured interview questions for students*

Following the collection of all interview audio recordings, the interviews were transcribed using a third-party transcription software and all responses to the interview questions, from both the teacher and students, were organized and analyzed using Holistic coding techniques (Saldaña, 2013) to explore the experiences of those involved with the intervention. Specifically, key trends, themes, and/or ideas were parsed out for further analysis and potential triangulation with other findings identified in the quantitative data analysis.

Findings

The findings, taken from both the quantitative and qualitative data collected during this study, are presented here in alignment with the corresponding research questions. We present here the results from all associated data sources—both quantitative and qualitative—as well as the implications for the overarching investigation. Our research questions centered on exploring the impacts, if any exist, of the Smart Clubhouse activity on teacher and student perceptions of STEM and CS as well as those related to gender. In light of the exploratory nature of this work we determined to use an alpha level of $p<.10$ to determine significance. Fully recognizing the limitations associated with a higher alpha level, in addition to the potential presence of any number of lurking and outside variables during the course of our lengthy intervention (thirteen weeks), these results are shared with the intent of exploring our questions and fostering further research, effort, and conversation around these topics.

Qualitative Findings: Teacher interview

The teacher was interviewed to explore the impacts, if any, of the intervention on their perceptions of STEM and CS. We were specifically interested in exploring the teacher's comfort level with the STEM and CS content in light of the noted legislation and other CS requirements. This exploration was accomplished through the semi-structured interview and associated holistic coding of the teacher's responses. Several themes emerged which provide insight into the teacher's experience; these are shared below with illustrative examples of each.

Holistic Idea 1: The teacher underestimated the student's abilities in STEM and CS. The teacher made several remarks highlighting that she was "surprised that they did as well as they did" and that she felt she "underestimated particular student's ability in [STEM] area[s]." The teacher noted the high-level of difficulty in the project but also talked about the benefits, to both her and the students, of such a project:

> It also showed me good and bad, but resiliency among my students, what kids really have that because even if they didn't know how to do it, I could see how do they problem solve? How did they get help? What were their strategies? So that was interesting, and I think for some of them it was interesting too because they're used to things being relatively easy for them, and I try to challenge them, but I think the whole process, there was never a part where they were like, Oh, this is going to be easy.

Holistic Idea 2: The teacher felt more comfortable, after the project, in pursuing future STEM and CS projects. The teacher mentioned multiple instances of being "uncomfortable" or "not knowing the answers to the student's questions" during the course of the project but also noted that her own comfort level had increased as a result. She shared:

> ...there were a lot of points where I'm like, I can't answer that question because I don't know what I'm doing. Especially with coding, but I haven't done any... I've never coded. It's been something I wanted to try, especially with this group of kids. So it was good for me, kind of forced me to try some things as well. But it was also hard not to know how to help them…

> I think I learned programming as well. I think I learned to be more comfortable with that and that process. I think I'd be more confident to go use the maker space by myself because I'm like, well, we all survived that. So, I think I could probably make this work… But I think I learned that would probably be the biggest takeaway I have is just being more comfortable with that process and that space in our building.

Holistic Idea 3: The teacher connected the project with lessons within her classroom. The teacher made several remarks highlighting how the project tied into other standards or topics that she had taught throughout the year. For example, she stated:

> I will say that some of the things that were covered, like you talked about circuits and needing a complete circuit and even similar work with fractions, those are things that I am going to try to cover, or a concept that we can refer back to this project when those things come up.

> And since I teach a two-year cycle, I don't get to electricity every year. So this is a good way to cover something like that, in a different way rather than the unit that I particularly always do because now they've had exposure to all that and on testing they would be able to answer the necessary questions without having been taught it from me.

Holistic Idea 4: The teacher viewed this project as an authentic programming opportunity. The teacher mentioned that she and her students had been provided with limited prior experience programming, but not at the level provided by this project. The teacher mentioned the following in her interview:

> I did have Makey Makeys in my other school, which they involve some minor programming, but I never delved really deep into that because you could make the Makey Makeys do all sorts of sounds when different things happen. But I never really was comfortable or confident enough to try that. So we did a lot of preexisting, pre-created

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> programs with them…this was way different[from Scratch programming] and way more complex. So I think they got a taste of, I know it gets way more complicated, but a tastes of how much more in depth coding can be…the programming component of nesting I thought was really fascinating. A lot of them hadn't done that. They could with relative ease, do programming pieces like singular. But when they had to put them all together and explain why certain things had to be nested where I think it made sense, but they hadn't really thought through it like that.

Quantitative Findings: Student survey responses.

While the perceptions of the teacher have significant impacts on student learning, it is also useful for teachers to understand the effects of these activities on students' perceptions in order to better support student development. In order to investigate the impacts of the intervention on student perceptions of STEM and CS, a paired samples t-test was conducted using the student pre- and post-study responses to the modified S-STEM questionnaire. While the majority of responses did not reveal any statistically significant difference between the pre- and post-study survey responses, the analysis revealed specific questions demonstrating significant differences in student responses. These questions, from the modified S-STEM survey, and the associated statistical results, are shared herewith.

Question 18. I can understand most subjects easily, but science is hard for me to understand. There was a significant difference in student responses to this question before (M= -.75, SD= 1.19) and after the intervention (M = -1.22, SD= .99), t (22) = -2.0057, p = 0.057. Students, overall, disagreed significantly more with this question after the intervention. The change in student responses to this statement following the intervention, which is negatively weighted, suggests that they did not agree with the idea that other subjects were easy to understand while science was difficult.

Question 19. In the future, I could do harder science work. There was a significant difference between student pre- (M= .95, SD= .93) and post-study responses to this question (M = 1.43, SD = .66), t (22) = 2.5543, p = 0.018. Students' responses shifted significantly in a positive direction suggesting their belief that they could do harder science work in the future grew.

Question 21. I believe that girls can be good at science**.** There was a significant difference between students' responses about girl's aptitude for science before (M=1.65, SD = .65) and after the intervention (M= 1.39, SD = .99), t (22) = 1.8166, p = 0.083. Significant change in student responses was negative suggesting the students felt significantly less confident in girls' ability to be good at science following the intervention

Question 32. I believe that girls can be good at engineering and technology. Similar to question 21, our analysis showed a significant difference between students' responses (M= 1.65, SD =.65) and after the SMART clubhouse unit (M= 1.43, SD = .95), t (22) = 2.011, p = 0.057. As with question 21, the students' confidence in girls' abilities in engineering and technology were significantly less following the intervention than before.

Question 41. I believe that girls can be good at computational thinking. Finally, when asked about girls' capacity in computational thinking, the student analysis showed a significant difference between pre- (M= 1.65, SD = .65) and post-study responses (M= 1.39, SD = .99), t (22) = 1.8166, p = 0.083. Like science, technology, and engineering, the responses suggest students felt significantly less confident in girls' ability to be good at computational thinking following the intervention.

Qualitative Findings: Student interviews.

In addition to the quantitative survey data, the findings from the semi-structured interviews with the students were used to explore our research questions. Holistic coding approaches were used to investigate student perceptions of a variety of topics focused on within the intervention (see Figure 2); this coding approach entails applying a single code to a larger unit of data, which captures the overall essence/idea of the contents (Saldaña, 2013). The findings, obtained through this investigative approach to the interview responses, are shared below with illustrative examples of each.

Holistic Idea 1: Student either liked building or programming, but not both. When asked what they liked/disliked about the project, the students made an interesting distinction - drawing a line between the "building" portion of the project and the "coding" portion. While almost all students interviewed noted that all aspects of the assignment were challenging, four out of the nine interviewed explicitly stated that they liked either building or coding and disliked the other. For example, Student 1 stated: "I think I liked the coding and I didn't really like the building" and Student 9 said:

> I really liked building it, but I didn't really like nesting [an aspect of the coding portion], because I think it was just really hard and complicated.

Perhaps unsurprisingly, when asked later about the potential for pursuing careers in these fields the student interviews suggested that they were interested in a career field related to the aspect of the assignment they enjoyed. Student 9, who liked the building but not the programming, remarked:

> I really want to be an engineer when I grow up and I want to build things and make things. And I think [this project will] really help me.

Alternatively, some students had preference for one portion (e.g., coding or building) but saw the potential for pursuing a career in either field. Student 12 indicated:

> I really liked building, because it was a little challenging at first but then you caught on those steps and it was really fun. And then I kind of dislike some of the programming, because it was really hard.

When asked about potential career options in the future, Student 12 touched on both building and programming:

> [Coding] was very fun and like it was different than... I'd never done something like this before. I've never built my own little house. I would definitely think about maybe I would be a programmer, like more working with technology and all of that. Maybe I would do building, not sure about [that].

This difference suggests that teachers may be able to help students by discussing the differences between these skills and how they connect to potential career paths.

Holistic Idea 2: Students accurately connected the assignment to STEM fields. When asked about potential connections between the project and STEM content areas the interviewees provided many examples. Students linked "housing (Student 1)" and "electricity and computers

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(Student 21)," to Science and "electrical current (Student 1)," and "computers (Student 21)" to Technology. However, the most common response from students for both "Science" and "Technology" was "coding."

When asked about "Engineering," student responses centered on "building things." For example, when asked about any potential connections between the project and "Engineering," Student 7 responded:

> The building and all the steps. I didn't even know that there was studs in a wall. I thought they just put a bunch of sticks in there and then put the wall together.

Similarly, Student 12 answered this question about engineering by stating:

> You have to scale everything down and that was definitely engineering. And then you have to build, of course you have to like get all the right placements, have the right spacing, make sure that doors like in the right proper little pieces.

Some students connected Mathematics with "variables" and "distances." However, the majority of student comments related to Mathematics centered on "scaling." This was perhaps unsurprising as scaling was a central aspect of the assignment and required significant effort on the student's part (see Table 1). Students' comments included ideas such as "the dimensions had to be perfect or else it wouldn't work" (Student 7) and

> Sizing down, like to get that, even that little or little ruler you use to size everything down (Student 12)

> To equal the size of this miniature house to the big house because we had to divide everything by fractions, and we had to make it a smaller version (Student 20)

The knowledge that students are able to accurately connect the applied tasks they are completing to STEM concepts can provide teachers with confidence that these activities support students' learning progressions.

Holistic Idea 3: Students were proud of their effort in doing something difficult. Consistently, throughout the interview responses, the students demonstrated pride in tackling difficult tasks – usually identified as either the building or the coding portions. Teachers can authentically reenforce these feelings to further increase student self-efficacy. Several comments illustrate this overarching sense of pride; for example, students commented:

> I thought it was easy and like JavaScript was like, 'Hm, I could probably learn that in a day or something.' But now that I've seen the whole thing of things you could use and how to program a house, I feel it's a lot more difficult. But I feel like it's a little bit easier for me to get through the difficult stuff because of this (Student 20).

> [my dad] was an engineer growing up, so he always knew all this fancy stuff and I didn't know any of it and my sister knew a little, but I never knew anything. So, I got to learn everything. And now my dad is proud of me, because I actually know some stuff he does... I like the different studs sometimes like or like building just in general. I tell him all the stuff I build. Like if I finished building something today, I'll tell my parents and he gets really excited. I finish coding something, I'll be also really excited (Student 12).

> It was really hard, but it was fun and I always had people who were there to help me. And it ended up being fun and now I know a lot more than I did when we started (Student 18).

Discussion

This research set out to explore the potential impact of an educational intervention—which centered on building and automating a scaled clubhouse—on student and teacher perceptions of STEM and CS fields. Further, we sought to investigate the impacts, if any existed, on these perceptions relative to gender among the students. Findings were derived from both quantitative and qualitative sources of information from both the students and teacher.

Following a 13-week intervention, consisting of more than 30 hours of class time, activities, worksheets, and lessons, there were notable impacts on the teacher or student's perceptions of STEM and CS (as collected through the interviews and modified S-STEM survey). The teacher, when interviewed, shared two important insights: 1) the students could do more than she had initially believed and 2) this intervention was an effective way to help her feel comfortable implementing STEM and CS activities in her classroom. The teacher was impressed with what the students were able to accomplish and noted the difficult nature of the assignment, she shared:

> And it was never, I think overwhelming because you introduced it all slowly over time. But there was never a stage where they could just go on cruise control. They had to really be on the whole time. So that was fun to watch. I love to hear how exhausted they were at the end. Every time that we worked, they're like, "Oh, my brain hurts so bad." Which is awesome. I mean, brain science shows that that's how you grow your brain. So I think they probably grew their brains quite a bit.

The teacher also noted that, although she was uncomfortable with the content at the beginning, by the end she was prepared to implement future STEM and CS activities. This finding suggests that the approach noted in this article, namely a hands-on classroom intervention with guidance, may be a feasible approach to future professional development. Additional research into the implications and potential of such an approach is needed – especially considering the mounting pressures on K-12 educators to integrate such content into their classrooms.

Findings derived from the student interviews were generally positive as well; students were proud of their capacity to "do something hard" and they were able to accurately connect the classroom intervention activities with associated STEM and CS fields. Additionally, we noted that students were generally inclined towards either "building" or "coding" but not both. Students who explicitly mentioned liking one (building or coding) almost always mentioned not liking the other – this was interesting as STEM and CS both draw on skills contained in both "building" and "coding." Perhaps students had preconceived notions of their own abilities (i.e., I am good with my hands or I am good with computers) and these carried over into their own experiences with the clubhouse. Alternatively, it is possible that the thinking required for the coding was different enough from that required for designing and constructing a physical model that some students were naturally more gifted or inclined than others. It was interesting to note that these preferences (e.g., building or coding) were not gender-specific, with both males and females similarly identifying one or the other as their preference.

Despite questions about gender and STEM or CS fields, very little significant information was derived from the students – in either the interview or questionnaire. Students were asked specifically about their perceptions of males or females and the various fields with very few significant responses. While we wondered if the presence of the female student researcher may be significantly impactful on student perceptions, few significant positive gains were found. However, we also recognize the possibility that negative perceptions could have been solidified or

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fostered regardless of the makeup of the research team – these ideas and the potential implications deserve further exploration, especially considering the pressures on integrating these concepts into K-12 classrooms.

Of those questions on the survey that revealed significant differences in student answers before and after the intervention, the majority demonstrated a negative impact, suggesting the students were less confident after the intervention than before. Specifically, the student's perceptions of girl's ability to do science, engineering and technology, and computational thinking were all significantly lower following the intervention. This finding may be attributed to a variety of things but highlights an important idea: just because students participate in an activity successfully does not mean their perceptions of their own, or their classmates, capabilities will increase. We noted that all female students in the class were successful in the project. Further, we noted that the student researcher was a female and served as an example for students of success in these STEM and CS fields; finally, the classroom teacher was also female and demonstrated many of the associated activities for her students. Despite these examples, the overall perceptions of students in the areas noted, decreased significantly during the course of the 13-week intervention. Further investigation into this finding is needed to adequately understand why such a decrease occurred, especially in light of the generally positive qualitive interview findings.

Positive statistical significance was found for two questions related to science – in both cases the students were more confident in their abilities to do science following the intervention. Although the intervention revolved around STEM and CS in general, and did not specifically center on Science, these were the only two questions demonstrating significant positive increases following the intervention. Recognizing the potential for a variety of external factors to influence these perceptions, we also posit that the activities associated with this intervention may have exposed students to new ideas, concepts, and processes and thus positively influenced their own perceptions. Additional research into the implications of these findings is needed to clarify the connection, or lack thereof, between the project and student's science perceptions.

Further, we noted that while these findings were significant in providing valuable information, they did not provide sufficient information to explain the reason for the associated data. Further investigation of these ideas, findings, and the shared research questions is worthy of pursuit. Specifically, we note that robust research—both qualitative and quantitative—may yield further explanation around these ideas. For example, following a review of the data, we hypothesized that as students' computational thinking capabilities improved their perceptions of STEM and CS also shifted. However, data should be collected before any concrete conclusions are reached and shared. Use of an interview instrument to measure computational thinking could determine if computational thinking acts as a mediator between student experiences and student ability perceptions in STEM and CS. Additional, or different, quantitative instruments may also shed additional light on different facets of this experience.

Conclusion

Given the mounting pressures, discussions, and legislations surrounds the integration of computer science into K-12 classrooms there is a need for robust research into both *what* should be done and *how* it can be effectively accomplished (Nager & Atkinson, 2016). We presented the findings from one educational outreach initiative with elementary students and their classroom teacher. We hypothesized significant positive gains in student STEM and CS interest and were especially interested in the potential for increases in perceptions surrounding females in light of the presence of a female student and teacher. However, most of our significant findings were negative in direction – we found it especially intriguing that perceptions of female students to "be good at" Science, Engineering and Technology, and Computational Thinking were all significantly less confident following the intervention despite the presence of multiple female role models (e.g., the teacher and student) for the duration of the project.

We identified several questions from this research which we feel are important areas for exploration in light of the myriad of efforts around STEM and CS. For example, maybe there were outside influences that caused such a decrease? Perhaps the intervention was difficult enough that it dissuaded students—who were initially fairly confident in their abilities—from future endeavors? Is it possible that a different project, approach to coding, or age range would produce different findings? Future research in this area can build on the findings from both the quantitative and qualitative efforts in this work and explore potential avenues and approaches for elevating students' perceptions of, and abilities in, STEM and CS fields.

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APPENDIX A

ADMINISTERED STEM QUESTIONNAIRE

DIRECTIONS: There are lists of statements on the following pages. Please mark your answer sheets by marking how you feel about each statement. For example:

Example 1:	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I like engineering	○	○	○	○	○

As you read the sentence, you will know whether you agree or disagree. Fill in the circle that describes how much you agree or disagree.

Even though some statements are very similar, please answer each statement. This is not timed; work fast, but carefully.

There are no "right" or "wrong" answers! The only correct responses are those that are true for you. Whenever possible, let the things that have happened to you help you make a choice.

PLEASE FILL IN ONLY ONE ANSWER PER QUESTION.

Math

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1. Math has been my worst subject.	○	○	○	○	○
2. When I'm older, I might choose a job that uses math.	○	○	○	○	○
3. Math is hard for me.	○	○	○	○	○
4. I am the type of student who does well in math.	○	○	○	○	○
5. I can understand most subjects easily, but math is difficult for me.	○	○	○	○	○
6. In the future, I could do harder math problems.	○	○	○	○	○
7. I can get good grades in math.	○	○	○	○	○
8. I am good at math.	○	○	○	○	○
9. I believe that boys can be good at math	○	○	○	○	○
10. I believe that girls can be good at math	○	○	○	○	○

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Science

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
11. I feel good about myself when I do science.	○	○	○	○	○
12. I might choose a career in science.	○	○	○	○	○
13. After I finish high school, I will use science often.	○	○	○	○	○
14. When I am older, knowing science will help me earn money.	○	○	○	○	○
15. When I am older, I will need to understand science for my job.	○	○	○	○	○
16. I know I can do well in science.	○	○	○	○	○
17. Science will be important to me in my future career.	○	○	○	○	○
18. I can understand most subjects easily, but science is hard for me to understand.	○	○	○	○	○
19. In the future, I could do harder science work.	○	○	○	○	○
20. I believe that boys can be good at science	○	○	○	○	○
21. I believe that girls can be good at science	○	○	○	○	○

Engineering and Technology

Please read this paragraph before you answer the questions.

Engineers *use math and science to invent things and solve problems. Engineers design and improve things like bridges, cars, machines, foods, and computer games.* ***Technologists*** *build, test, and maintain (or take care of) the designs that engineers create.*

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
22. I like to imagine making new products.	○	○	○	○	○
23. If I learn engineering, then I can improve things that people use every day.	○	○	○	○	○
24. I am good at building or fixing things.	○	○	○	○	○
25. I am interested in what makes machines work.	○	○	○	○	○
26. Designing products or structures will be important in my future jobs.	○	○	○	○	○
27. I believe that boys can be good at engineering and technology	○	○	○	○	○
28. I want to be creative in my future jobs.	○	○	○	○	○
29. Knowing how to use math and science together will help me to invent useful things.	○	○	○	○	○
30. I believe I can be successful in engineering.	○	○	○	○	○
31. I am curious about how electronics work.	○	○	○	○	○
32. I believe that girls can be good at engineering and technology	○	○	○	○	○

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Computational Thinking

Please read this paragraph before you answer the questions.

Computational Thinking *is a problem-solving process that is used in many areas such as developing computer applications. Those who work with computational thinking may program a device to perform a function, develop a program to play a video game, or automate (make something happen without human help) a process.*

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
33. I can break down large ideas into smaller parts	○	○	○	○	○
34. I like to find patterns and trends in things.	○	○	○	○	○
35. When I observe a pattern I can identify the rules of the pattern.	○	○	○	○	○
36. I am curious about how computers, machines, and electronic devices work.	○	○	○	○	○
37. I feel good when I design or make something that uses technology.	○	○	○	○	○
38. I can develop instructions for solving a problem or completing a task.	○	○	○	○	○
39. I can use models and simulations to see how things work.	○	○	○	○	○
40. I like to collect data to help me make a decision.	○	○	○	○	○
41. I believe that girls can be good at	○	○	○	○	○

computational thinking					
42. I can program something to perform a task.	○	○	○	○	○
43. I believe that boys can be good at computational thinking	○	○	○	○	○
44. I can visualize collected data to better understand something.	○	○	○	○	○
45. I believe I can be successful in computational thinking.	○	○	○	○	○

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