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Creating Opportunity from Challenge: A Virtual Approach to Building STEM Confidence and Skills

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Abstract

The transition to virtual learning during the COVID-19 pandemic posed unique challenges for STEM education, particularly in maintaining hands-on, interactive learning experiences. This paper describes and presents preliminary findings of the implementation and outcomes of an online coding camp designed to empower high school students by enhancing their coding skills, problem-solving abilities, and self-confidence. Drawing on iterative design and student-centered learning strategies, the camp utilized breakout rooms, "papercraft" activities, personalized feedback, and collaborative exercises to foster engagement and confidence.

Pre- and post-surveys were administered during the 2023 and 2024 iterations of the camp to assess changes in students' confidence across key areas. The results indicate significant improvements in students' confidence in coding tasks, algorithm development, and problem-solving. Notably, the 2024 camp demonstrated greater gains in coding-specific skills, likely due to the increased use of breakout rooms that provided targeted support and peer collaboration. These findings align with existing research on the effectiveness of small-group interactions and flexible learning environments in virtual STEM programs.

This study contributes to the discourse on virtual STEM education by highlighting the importance of adaptable, interactive learning experiences that foster student engagement and self-confidence. The coding camp was developed and distributed through a partnership between Texas Tech University and the University of Memphis, with funding from the National Science Foundation under Grant No. 2105766. The success of the camp underscores the potential for virtual programs to help prepare students for future academic and career pursuits in technology-driven fields. Future iterations will explore the balance between collaborative learning, hands-on activities, and independent problem-solving to further support comprehensive skill development in pre-college STEM education.

Introduction

The rapid growth of technology-driven industries has increased the need for robust STEM (Science, Technology, Engineering, and Mathematics) education, particularly at the pre-college level. In recent years, coding and computer literacy have become essential skills for students, laying the groundwork for future success in STEM fields. However, the COVID-19 pandemic disrupted traditional learning methods, resulting in a swift transition to various online formats. This disruption created unprecedented challenges, especially in maintaining or replicating the hands-on, interactive nature of STEM learning experiences [1].

Online versions of STEM camps emerged as the obvious, pragmatic solution to these challenges, attempting to provide students with opportunities to engage in coding, robotics, and other technical subjects remotely. Developed and distributed through a partnership between Texas Tech University and the University of Memphis, and funded by the National Science Foundation (NSF) under Grant No. 2105766, our coding camp aimed to empower high school students through an immersive, online coding experience. While the camp was initially designed to teach fundamental programming skills, the overall approach was structured to boost students' confidence in their ability to solve complex problems, collaborate with their peers, and develop an understanding of computer science principles. In an effort to move beyond a solely screen-based experience, the camp incorporated "papercraft" activities, such as a printable binary increment Turing machine, logic gate “mazes” and paper versions of half and full adder circuits. These tangible tools provided a bridge between abstract concepts and concrete understanding, reinforcing key computational principles through literal hands-on learning.

This paper examines the implementation and outcomes of the coding camp, focusing on the efforts made to enhance the virtual learning experience and their impact on student confidence and skill development. By analyzing pre- and post-survey data, we aim to provide insights into how an iterative, student-centered approach can address the challenges of virtual STEM education and contribute to the broader discourse on pre-college engineering education. Our findings emphasize the importance of adaptable, interactive learning experiences that not only impart technical knowledge but also foster self-confidence and a passion for STEM.

Background

The arrival of the COVID-19 pandemic in 2020 forced educators worldwide to hastily transition from traditional classroom settings to online learning environments. STEM programs, in particular, faced the challenge of replicating the hands-on collaborative experience long-deemed necessary in this field. Online STEM camps quickly became the de-facto solution, attempting to provide students with opportunities to engage in coding, robotics, and other technical subjects without leaving their homes. However, the effectiveness of these virtual programs depended heavily on their ability to adapt pedagogical strategies to the online format [2].

Several studies have highlighted the importance of carefully designed virtual learning environments for maintaining student engagement and learning outcomes in STEM education. For example, Lowe et al. [2] described how a design-based research approach enabled rapid adaptation and iterative improvements in virtual STEM camps, highlighting the need for flexibility and student-centered learning experiences. Their work emphasized the significance of breakout rooms, personalized support, and hands-on activities in overcoming the inherent limitations of online learning. Similarly, Chiang [3] demonstrated that online STEM camps could significantly enhance students' self-efficacy and computational thinking when structured to promote active engagement and cross-disciplinary learning.

Our coding camp was developed within this context, initially planned to launch as an in-person experience in 2021. When the pandemic necessitated a shift to a virtual format, the camp underwent a series of adaptations aimed at preserving its interactive and experiential learning focus. Drawing on insights from the literature, we implemented a student-centered approach that leveraged small-group interactions, personalized feedback, and a focus on problem-solving to enhance the virtual learning experience. Early iterations of the camp (2021–2022) involved an exploration of different tools and strategies to engage students effectively, such as using the P5.js library for creative coding exercises and incorporating live Zoom sessions for synchronous instruction and support.

By 2023, our experience and observations had led to a refined structure that emphasized active learning and peer collaboration. We introduced breakout rooms during Zoom sessions, allowing for more personalized instruction and small-group discussions. This approach aligns with the findings of Lowe et al.[2], who identified breakout rooms as a critical component of effective virtual STEM programs. Moreover, we recognized the importance of self-confidence in students' learning outcomes, as highlighted by Chiang, et al. [3]. Consequently, the camp's curriculum was designed to build students' confidence in tackling coding tasks and solving complex problems, fostering a growth mindset in a supportive, collaborative environment.

The iterative nature of the camp's development underscores the importance of flexibility and adaptability in educational design, especially in the face of unprecedented challenges like the pandemic. This paper focuses on the camp's 2023 and 2024 iterations, analyzing the impact of the program's structure and instructional strategies on student outcomes. By examining pre- and post-survey data, we aim to contribute to the ongoing conversation about best practices in online STEM education and the potential for virtual programs to empower the next generation of STEM learners.

Methodology

The coding camp was designed to engage high school students in foundational programming concepts through an interactive, student-centered online learning environment. This section outlines the participants, camp structure, tools and resources, and data collection methods used to evaluate the camp's effectiveness in enhancing students' confidence and coding skills.

The camp targeted high school students with an interest in coding and STEM fields, welcoming participants with varying levels of prior programming experience. The participants in both the 2023 and 2024 iterations of the camp were recruited through online channels, including social media, school networks, and community organizations. No prior coding experience was required, which allowed for a diverse group of students. In total, the camp hosted 17 students in 2023 and 11 students in 2024, reflecting a range of genders, backgrounds and skill levels.

The camp spanned two weeks, with daily two-hour sessions conducted entirely online. Each session was designed to be highly interactive, incorporating live instruction, hands-on coding exercises, “concept surveys” (quizzes), collaborative learning opportunities, and "papercraft" activities. The curriculum was structured around the P5.js library, an open-source JavaScript library and free online editor that facilitates creative coding through visual and interactive projects. Daily activities included coding challenges, troubleshooting tasks, collaborative problem-solving exercises, and physical "papercraft" tools to reinforce learning. The emphasis was on fostering an environment where students could experiment, ask questions, and learn from both instructors and peers.

Papercraft Activities

To complement the digital coding exercises and align with the camp's hands-on theme, we incorporated multiple printed "papercraft" activities. These activities provided a tangible, visual way to explore abstract computing concepts, reinforcing students' understanding of algorithms, binary arithmetic and logic gates:

Turing Machine: A printable model that allowed students to manually simulate a simple Turing machine, which could increment any binary number. This activity helped students begin to understand the concept of algorithms and exposed them to the mechanics of binary computation to provide insight into how machines process information.

Logic Gate “Mazes”: Printable diagrams of various logic gate structures were created. The mazes facilitated discussion not only of the logic gates themselves but laid the groundwork for later discussion of object-oriented concepts such as encapsulation and abstraction.

Half Adder Diagram: A printed diagram used to demonstrate the basic concept of adding two binary bits. This hands-on tool facilitated an understanding of how simple logic gates work together to perform binary addition. Anecdotally, one student remarked that it was incredible to be able to “do math by drawing lines.”

4-bit Full Adder: An extension of the half adder, this printed model allowed students to explore the complexity of adding multi-bit binary numbers. By interacting with the full adder diagram, students gained a deeper appreciation for the processes underlying more complex arithmetic operations in computing.

These "papercraft" activities served as an effective bridge between the abstract nature of coding and the concrete logic that underlies computational processes. By physically engaging with the concepts, students could better grasp the fundamentals of binary arithmetic, logic gates, and the broader principles of computing. It has been found that a blended approach to learning environments such as this can be highly effective [5].

Tools and Resources

The primary coding environment used in the camp was the P5.js web editor, accessible via the p5js.org website. This tool was chosen for its user-friendly interface and ability to provide immediate visual feedback, which is crucial for maintaining engagement in an online setting. Moodle was employed as the learning management system, where students could access daily lesson materials, submit assignments, and receive feedback from instructors. To support students' learning outside of live sessions, we produced a series of instructional YouTube videos that covered key programming concepts and coding tutorials [10]. These and other resources were made freely available on EngineeringTechnology.org [11], providing an additional layer of support and allowing students to revisit topics at their own pace.

To assess the impact of the camp on students' confidence and skills, we administered pre- and post-surveys in both the 2023 and 2024 iterations of the camp. The surveys included a series of Likert-scale questions (1 = "strongly disagree" to 5 = "strongly agree") designed to measure students' self-confidence in areas such as:

- Problem-solving (e.g., "When difficult problems are given to me, I am confident that I will be able to understand them"),
- Coding tasks (e.g., "I am confident that I can complete coding tasks given to me"),
- Algorithm development (e.g., "I understand how to develop an algorithm for a computer program"),
- Communication and collaboration (e.g., "I am confident that I can communicate with others to solve problems").

In addition to quantitative measures, open-ended questions were included to gather qualitative feedback on students' learning experiences and perceived challenges. The survey data was analyzed to identify changes in students' confidence levels and to compare the effectiveness of the instructional strategies used in the 2023 and 2024 camps. This mixed-methods approach allowed for a comprehensive evaluation of the camp's impact on students' learning and engagement.

Results

The effectiveness of the coding camp was evaluated using pre- and post-surveys administered to participants in both the 2023 and 2024 camp sessions. These surveys aimed to measure changes in students' self-confidence across key areas, including problem-solving, coding tasks, algorithm development, and communication. The data collected provides insight into the camp's impact on student confidence and highlights the effectiveness of the modifications made to the camp structure.

Both the 2023 and 2024 camps resulted in improvements in students' confidence across all key areas measured by the surveys. However, the 2024 camp demonstrated greater overall gains, likely attributed to the introduction of additional breakout rooms during Zoom sessions, which facilitated more personalized instruction and peer collaboration. This aligns with findings from prior studies, which emphasize the value of small-group interactions and targeted support in virtual STEM programs [1].

The students' confidence in their ability to solve complex coding problems was measured through Question 3: "When difficult problems are given to me, I am confident that I will be able to understand them." In both years, participants reported increases in confidence from pre- to post-surveys.

- 2023: Pre-camp score of 3.7 and a post-camp score of 4.2, resulting in an improvement of 0.5 points (95% CI: 0.19 to 0.88).
- 2024: Pre-camp score of 4.2 and a post-camp score of 4.3, showing a smaller improvement of 0.1 points (95% CI: -0.58 to 0.84).

While the overall confidence in 2024 started higher, the relative improvement was more substantial in 2023. This suggests that the 2023 cohort may have experienced a more dramatic increase in problem-solving confidence relative to their starting point.

Several survey questions focused on students' confidence in completing coding tasks and understanding programming constructs. These included Question 2: "I am confident that I can complete coding tasks given to me," and Question 10: "I understand how to develop an algorithm for a computer program."

- Question 2 (Completing coding tasks):
  - 2023: Pre-camp score of 2.8 and a post-camp score of 3.9, resulting in a 1.1-point improvement (95% CI: 0.69 to 1.49).
  - 2024: Pre-camp score of 3.0 and a post-camp score of 4.4, showing a larger improvement of 1.44 points (95% CI: 0.55 to 2.34).
- Question 10 (Developing algorithms):
  - 2023: Pre-camp score of 3.9 and a post-camp score of 4.1, showing a modest improvement of 0.2 points (95% CI: -0.14 to 0.61).
  - 2024: Pre-camp score of 4.0 and a post-camp score of 4.4, resulting in a larger improvement of 0.44 points (95% CI: -.08 to 0.97).

These results indicate that the 2024 camp was likely more effective in boosting students' confidence in completing coding tasks and developing algorithms. The increased use of breakout rooms and personalized support likely contributed to this outcome, echoing the findings from

Lowe et al. [2] who highlighted the importance of small-group interactions in enhancing learning outcomes in virtual STEM education.

Question 8, which measured students' confidence in communicating with others to solve problems, showed improvement across both years:

- 2023: Pre-camp score of 3.6 and a post-camp score of 4.2, resulting in a 0.6-point improvement (95% CI: 0.25 to 0.94).
- 2024: Pre-camp score of 4.3 and a post-camp score of 4.3, with a negligible increase of 0.03 points (95% CI: -0.66 to 0.72).

While the improvement in 2024 was less pronounced, students in that cohort began with higher confidence in their communication skills. The 2023 camp's larger improvement in this area suggests that students who started with lower confidence in communication were able to make significant improvement during the camp.

Among all measured areas, confidence in completing coding tasks (Question 2) was the most statistically supported improvement across both years. The 2024 camp, in particular, demonstrated a significant increase of 1.44 points (95% CI: 0.55 to 2.34), suggesting that the enhanced instructional strategies, including expanded breakout rooms, were especially effective in building student confidence in coding tasks.

Other areas, including problem-solving confidence (Question 3) and communication skills (Question 8), also showed gains across both years, although their confidence intervals indicate some variability in responses. While the 2024 cohort had higher starting confidence in communication, the 2023 camp demonstrated stronger relative improvements in this area.

Comparing 2023 and 2024

Overall, the 2024 camp demonstrated more substantial gains in coding-specific skills and problem-solving confidence. The introduction of more breakout rooms in 2024 provided greater opportunities for personalized instruction, which appears to have contributed to these outcomes. However, the 2023 camp showed stronger improvements in areas such as problem-solving and communication, possibly due to the cohort's initial confidence levels and the adaptation process inherent in the early stages of transitioning to virtual learning.

Discussion

The findings from the 2023 and 2024 iterations of the coding camp provide valuable insights into the impact of instructional strategies on students' confidence in coding, problem-solving, and communication in a virtual learning environment. The results highlight the effectiveness of an iterative, student-centered approach, particularly the use of breakout rooms, in enhancing learning outcomes and align with existing research on best practices in virtual STEM education.

Impact of the Camp's Instructional Design

The increased use of breakout rooms in the 2024 camp appears to have had a significant positive impact on students' confidence in completing coding tasks and developing algorithms. This aligns with findings from Lowe, et al. [2], which emphasize the importance of small-group interactions and personalized support in online STEM programs. By creating an environment where students could engage in focused discussions, receive real-time feedback, and collaborate on problem-solving tasks, the camp leveraged the strengths of virtual learning to provide a more tailored and interactive experience.

The fact that the 2024 cohort showed greater improvements in specific coding skills suggests that the structure of breakout rooms helped mitigate some of the challenges inherent in virtual learning, such as the potential for disengagement and isolation. The personalized support and peer collaboration facilitated by this structure likely contributed to students feeling more confident in tackling complex coding tasks, as they had direct access to guidance and the opportunity to learn from their peers.

Implications for Student Confidence and Learning

The observed improvements in students' confidence in coding and problem-solving align with existing research on self-efficacy in STEM education [3], [6]. Self-efficacy plays a crucial role in students' willingness to engage with challenging tasks and persist in the face of difficulties [13]. By fostering a growth mindset and providing an environment that encourages experimentation and reinforces concepts through a multi-modal approach, it is thought that the camp contributed to enhancing students' belief in their ability to succeed in coding and computational thinking. Unfortunately, the survey instrument was not originally structured to assess self-efficacy, so these results, while implied in survey data, must be treated as anecdotal.

Additionally, while the survey results suggest an increase in self-confidence, this alone does not equate to proficiency. Although anecdotal evidence from student project submissions suggests that many participants applied the concepts effectively, a direct assessment of coding proficiency was not conducted as part of this study. Future iterations of the camp could benefit from integrating coding assessments or project-based evaluations to better understand the relationship between self-efficacy and actual skill development.

Alignment with Existing Research

The coding camp's iterative design and the positive outcomes observed align with broader trends in virtual STEM education, particularly the need for adaptable and student-centered learning experiences [2]. Similar to these studies, our camp demonstrated that a flexible approach—incorporating synchronous and asynchronous elements, breakout rooms, and direct feedback—can effectively support students' learning and engagement in a virtual setting.

Moreover, the camp's success in boosting students' self-confidence resonates with research emphasizing the role of confidence in STEM learning outcomes [3]. By creating an environment that nurtures students' confidence in their coding abilities, the camp contributes to the growing body of evidence supporting the utility of online STEM programs in preparing students for future academic and career pursuits in technology-driven fields.

Limitations and Future Directions

While the findings are promising, there are several limitations to this study. The reliance on self-reported data from the pre- and post-surveys introduces potential bias, as students' perceptions of their own confidence may not always align with their actual abilities. Additionally, the sample size for both the 2023 and 2024 camps was relatively small, which may limit confidence of the results. Further research with larger cohorts and more objective measures of learning outcomes, such as coding assessments or project evaluations, would provide a more comprehensive understanding of the camp's impact.

Future iterations of the camp could explore a hybrid approach, combining the strengths of breakout room interactions with opportunities for independent problem-solving. The survey instrument could be modified to evaluate self-efficacy, which began to become more central to the camp’s primary goals. Additionally, tracking students' long-term engagement with STEM following the camp would offer insights into the sustained impact of such programs on students' academic trajectories and career interests.

Conclusion

This study demonstrates the potential of online coding camps to enhance high school students' confidence in coding, problem-solving, and communication. By employing an iterative, student-centered approach that incorporated personalized support through breakout rooms and hands-on coding exercises, the camp effectively engaged students in an immersive learning experience. The findings from both the 2023 and 2024 iterations of the camp underscore the importance of flexible and adaptable instructional strategies in virtual STEM education, particularly in the context of the rapid shift to online learning necessitated by the COVID-19 pandemic.

The results indicate that the 2024 camp's increased use of breakout rooms significantly contributed to greater gains in coding-specific skills and self-confidence. These findings align with existing research, such as Lowe [2], which highlights the value of small-group interactions and targeted support in virtual learning environments. The observed improvement in students' confidence across both years suggests that virtual STEM camps can provide an effective platform for developing key skills and fostering a passion for STEM, provided that the program design prioritizes active engagement, collaboration, and personalized feedback.

While the camp demonstrated success in boosting students' confidence and coding abilities, the study also revealed the importance of balancing collaborative learning with opportunities for independent problem-solving. The 2023 camp's larger increase in problem-solving confidence points to the value of allowing students to face challenges and develop resilience in a supportive, less structured, learning environment. Future iterations of the camp should explore how to integrate these elements to provide a more comprehensive and balanced learning experience.

In conclusion, this study contributes to the growing body of research on virtual STEM education by highlighting effective strategies for fostering student engagement and self-confidence in an online coding camp. The iterative design and flexibility inherent in the camp's structure serve as a model for other pre-college STEM programs seeking to adapt to the evolving landscape of online education. By creating an environment that empowers students to experiment, collaborate, and build confidence in their abilities, virtual STEM camps can play a crucial role in preparing the next generation for success in technology-driven fields.

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