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Evaluation of Inquiry-Based and Constructionist Research Experiences for Engaging High School Students in Computer Science

Santiago Ospina Tabares, University of Illinois at Urbana - Champaign
Kathleen Isenegger, California State University, Chico

Dr. Kathleen Isenegger joined the Computer Science Department at California State University, Chico in 2025 as an Assistant Professor. She received her B.A. in Computer Science and Sexuality, Women's, and Gender Studies from Amherst College and Ph.D. in Computer Science at the University of Illinois at Urbana-Champaign. Her research is focused on broadening participation in computing through cultural and pedagogical interventions.

Brad Solomon, University of Illinois at Urbana - Champaign
Yael Gertner, University of Illinois at Urbana - Champaign

Dr Gertner joined the Computer Science Department at the University of Illinois in 2020 as a Teaching Assistant Professor. She received her B.S. and MEng in Electrical Engineering and Computer Science from MIT, and Ph.D. in Computer and Information Science at the University of Pennsylvania. She was a Beckman Fellow at the University of Illinois Urbana-Champaign. Her current focus is on broadening participation in Computer Science and Computer Science Education She has been developing materials and teaching for iCAN, a new program for broadening participation in CS for students who have a bachelor's degree in a field other than computer science.

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Abstract

Broadening participation in computer science (CS) requires learning environments that move beyond knowledge transmission and engage students in authentic disciplinary practices. Grounded in constructivist epistemology, this study integrates Inquiry-Based Learning (IBL) and constructionism to examine a faculty-mentored, inquiry-driven summer research program where high school students conducted authentic CS research and produced computational artifacts. Across two cohorts (2024–2025; N = 32), students worked in small teams on open-ended projects aligned with faculty research and presented their work publicly. Exploratory quantitative pre–post survey data from the 2024 cohort assessed CS confidence, interest, belonging, usefulness, and encouragement; preliminary findings suggest increases in CS usefulness and CS encouragement. Qualitative focus groups and final presentations, analyzed using reflexive thematic analysis, showed that students learned through iterative inquiry (questioning, testing, interpreting evidence, and communicating findings) and through building and refining artifacts (code, models, pipelines, and visualizations). Distributed mentorship and peer collaboration supported learning, while constraints such as limited time and ambiguous goals often led to productive struggle that strengthened problem-solving and research confidence. Overall, findings suggest that positioning authentic research as a learning methodology can broaden students' perceptions of CS as relevant and accessible, while supporting engagement in inquiry and early engineering design practices.

Introduction

Broadening participation in computer science and STEM remains a challenge, particularly at the high school level, where students' attitudes and perceptions of computing often shape future educational decisions [1][2][3]. Traditional instructional approaches based on knowledge transmission continue to dominate computing education, despite evidence that such approaches can limit deeper learning and student engagement [4]. Constructivist perspectives argue that learning occurs through students' active engagement with ideas, experiences, and projects, suggesting the need for learning environments that position students in the center of the learning experience [5].

Inquiry-Based Learning (IBL) and constructionism provide complementary frameworks for understanding learning in such environments. IBL centers learning on students' engagement in inquiry processes, including exploring problems, generating questions, collecting and interpreting evidence, and communicating findings [6][7]. Constructionism, grounded in constructivism, emphasizes learning through the creation of artifacts that represent and support knowledge construction [8]. Both frameworks align closely with the practices of computer science research, where understanding develops through iterative inquiry and through computational artifacts such as code, models, and visualizations.

This study examines a faculty-mentored, inquiry-driven summer research program in which high school students engage in authentic computer science research. The program was designed to reduce common barriers to inquiry-based learning by providing flexible mentorship, access to resources, and opportunities to engage in the full research process. The study is guided by two research questions: *(1) How does participation in a faculty-mentored, inquiry-driven computer science research program influence high school students' attitudes toward computing?* and *(2) What factors influence learning in a computer science program grounded in inquiry-based learning and constructionism?*

Theoretical framework

Constructivism and constructionism

Constructivism, originally developed by Piaget, is an epistemological perspective stating that individuals construct their own knowledge through a process of experimentation and adaptation between the mind of the individual and the external experiences [5]. Learning therefore evolves from a more intuitive and naive reasoning and develops while new experiences and information change the mental schemes previously known [5]. Piaget, therefore, centers learning in the individual and contrasts with instructional perspectives that argue that knowledge is transferred from teachers to students.

However, even when Piaget recognized the interaction between external stimuli and mental adaptation in knowledge development, his research focused mostly on the process of mental adaptation [5]. On the other hand, Papert, grounded in constructivism, focused on the external representations of learning [5]. He argued that individuals construct knowledge more effectively when they develop an artifact, which becomes a representation of knowledge [8]. This is what is called constructionism.

Constructionism therefore, centers the learning process in the individual while creating a product, giving the student agency over their learning [9]. Those artifacts allow learners to adapt the learning process to their preferences, allowing pluralism in the way they approach their learning. Artifacts also allow experiencing with different materials [10], and interaction between individuals through collaboration and public sharing [11].

Inquiry based learning

Rooted in constructivist epistemology, Inquiry Based Learning (IBL) is a pedagogical approach that centers the learning process in the student while engaging in activities of observation, collecting evidence, solving problems while applying critical thinking and logical reasoning, and communicating explanations to phenomena [6][7]. In other words, it implies conducting experiments and following the stages of the scientific method guided by research questions as a way to engage with concepts, develop creative thinking and develop more complex abstract knowledge [4][12].

Based on a systematic literature review conducted by Pedaste et al. [13], IBL encompasses five general phases that the student follows in their inquiry process. This include: 1) *Orientation,* which implies the introduction of the topic and learning challenge, leading to the formulation of the problem statement, 2) *Conceptualization*, which implies understanding the theoretical background of the problem and leads to the generation of the research questions and hypotheses, 3) *Investigation,* which implies exploration, experimentation, data collection and interpretation, 4) *Conclusion,* which implies drawing conclusions based on the data collected in the previous phase, and 5) *Discussion,* which includes communication of the findings and receiving feedback and reflection that implies evaluating the inquiry process and outcomes.

The inquiry cycle described by Pedaste et al. [13] parallels well established models of the engineering design process, which emphasize problem definition, ideation, modeling, testing, iteration, and communication [14]. In this sense, the research projects undertaken by students in this program can be understood not only as inquiry-based learning experiences, but also as early engagement in engineering design practices, particularly computational modeling, system evaluation, and optimization under constraints.

Integration of the theoretical frameworks for the study

This study is grounded in constructivist epistemology and integrates Inquiry-Based Learning (IBL) and constructionism to conceptualize authentic research as a learning methodology rather than an enrichment activity. Inquiry-Based Learning provides a process-oriented framework that positions students as active investigators who construct understanding through questioning, exploration, evidence-based reasoning, and reflection across the full inquiry cycle. Constructionism complements this process by emphasizing the role of designing and producing computational artifacts as a central mechanism for learning, allowing students to externalize, test, and refine their developing ideas through programs, models, visualizations, and presentations. Together, these frameworks align with the nature of computer science and engineering education research, in which knowledge is constructed through iterative inquiry and made tangible through public artifacts that embody conceptual and epistemic understanding. In the context of this faculty-mentored research program, IBL structures how students engage with open-ended problems, while constructionism explains how learning occurs through the creation, sharing, and reflection on computational products. Integrating these frameworks enables analysis of what factors influence learning through artifacts, engagement with disciplinary practices, and the development of computing and research identity among high school students.

Literature review

Constructionism in computing and engineering

Constructionism has a long tradition in the field of computing and engineering. Since its origins, Papert applied his constructionism perspective in studies using Logo, a programming language and environment in which students program artifacts and learn both programming and math concepts [15][16]. Papert focused on programming as he believed computers were a very powerful tool that allowed endless possibilities for adaptation and simulation [9]. This approach led to a long tradition of constructionism tools and methodologies for computing education that prioritize project creation and use of digital environments such as Scratch, which allows students to create products while engaging in computing concepts [17][18][19].

But the influence of constructionism goes beyond computing education and has impacted engineering disciplines as well. The influence in engineering is natural as the field places high importance on project based, hands-on experiences [20]. One of the most sound examples of this is the use of constructionism approaches in maker education. Maker education promotes the use of technology and the application of engineering processes to learn science, math, and computing in the creation of artifacts, while promoting a playful context, experimentation, student agency and a collaborative community [21][22][23].

Inquiry based learning in engineering

The literature reports positive evidence of the application of IBL in engineering education initiatives. Lou et al. [24] in a study conducted in an engineering undergraduate course, concluded that IBL increases students' positive perception of collaboration, enjoyment, engagement and concepts understanding. In their study, Sen et al [25] implemented a learning intervention in which students conduct a water turbine optimization task. They compared students receiving IBL instructions with students receiving traditional instruction, and concluded that those learning under IBL had higher gains in knowledge, problem solving, research skills, decision-making and critical thinking. Ahmed et al [26] in an intervention aimed to develop learning in software engineering, concluded that the use of IBL impacted positively learning performance. Lin et al [27] in a science and engineering course with children 5-5 years, concluded that IBL impacted science knowledge and competence motivation. Taken together, the evidence provided in these studies justified the use of IBL as a practical application of constructivism/constructionist learning, providing advantage in key educational outcomes such as disciplinary knowledge gains and soft skills.

Research gap and motivation for the study

The literature reviewed in this study demonstrates that constructivist approaches such as Inquiry-Based Learning (IBL) and constructionism have been associated with positive educational outcomes, including improved conceptual understanding, engagement, collaboration, and the development of disciplinary and transferable skills across computing and engineering contexts. However, as noted by Khalaf [4], traditional instructional approaches based on knowledge transmission remain dominant, despite evidence that they often limit deeper learning and the development of student confidence. This tension highlights the need for continued investigation of alternative pedagogical approaches that better align with constructivist theories of learning.

At the same time, existing research also points to significant challenges in the implementation of IBL, particularly within formal high-school education settings. These challenges include limited curricular flexibility, restricted access to resources, and difficulties students may face when engaging in open-ended inquiry without sufficient background knowledge or guidance [4]. Such constraints can hinder the effective implementation of IBL and may result in learner frustration or uneven learning outcomes. As a result, there is a need to explore learning contexts in which the structural limitations of formal schooling are reduced and where inquiry can be supported through alternative forms of scaffolding.

The present study addresses these gaps by examining a faculty-mentored, inquiry-driven summer research program in which high school students engage in authentic computer science research while developing computational artifacts. By situating learning within an informal research context and analyzing students' attitudes, learning processes, and artifacts across two cohorts, this study extends prior work by examining how IBL and constructionism function together as a learning methodology. In doing so, the study builds on existing evidence presented in the literature and responds directly to previously identified challenges by providing empirical insight into the opportunities and limitations of inquiry- and constructionist-based research experiences for high school students.

Summer research program

The intervention consisted of a summer faculty-mentored computer science research program designed to foster high school students' positive attitudes toward computing and readiness to pursue computer science in college, with the broader goal of increasing participation in the field. The program positioned authentic research as the central learning activity, rather than as an enrichment supplement, and sought to develop a replicable, low-cost model that could be adopted in similar contexts. To support this goal, the program emphasized flexible mentorship structures, sustained engagement with open-ended problems, and opportunities for students to engage in disciplinary practices aligned with inquiry-based learning and constructionism.

Students participated in the program by working in small teams of two or three and were paired with a faculty mentor who designed a research project related to their ongoing work. Faculty mentors guided students through activities characteristic of authentic computer science research, including learning to use disciplinary tools (e.g., programming and machine learning environments), completing coding tutorials, reading and discussing scholarly literature, exploring ethical and applied dimensions of computing, and working toward solutions connected to the mentor's research goals. While faculty met with students at least once every two weeks over a minimum six-week period, students were also expected to work independently for several hours each week. This structure supported inquiry-based learning by engaging students in the full inquiry cycle—exploring a problem, investigating data or systems, interpreting results, and communicating findings—while allowing flexibility in how inquiry was pursued.

Consistent with a constructionist approach, students' learning was centered on the creation of computational artifacts that externalized their developing understanding. These artifacts emerged through the research process and culminated in a final public presentation in which students shared their projects with faculty, peers, parents, and members of the university community. The final presentations were designed to encourage reflection, feedback, and pride in students' work, reinforcing the role of artifacts as both representations of learning and epistemic tools for sense-making. Throughout the program, additional community- and skill-building activities were facilitated by the program staff, including an orientation session focused on goals for research and a midpoint meeting that supported socialization, reflection, and preparation for presenting work.

The program was intentionally designed to reduce barriers commonly associated with inquiry-based learning and research experiences at the high-school level. Recruitment was conducted in partnership with a local public high school teacher to ensure that students who might not otherwise access such opportunities were informed and encouraged to apply. A holistic application process emphasized interest, commitment, and readiness rather than prior coursework or grades, and scheduling flexibility accommodated students' summer obligations such as employment, travel, and extracurricular activities. Faculty mentors and students independently determined meeting modalities and timelines, allowing inquiry to unfold in ways that were responsive to both participants' constraints. Together, these design features supported sustained engagement in inquiry and artifact construction within an informal learning context, addressing previously identified challenges of implementing inquiry-based and constructionist approaches in more rigid educational settings.

Recruitment and participants

Students were recruited through a partnership with a computer science teacher at a large local public high school near the university in central Illinois. The school serves a racially and ethnically diverse student population and has lower college matriculation rates than comparable schools, despite its proximity to an R1 university. The teacher partner shared information about the program with students enrolled in computing courses and related extracurricular activities and encouraged them to apply.

The application process was designed to emphasize interest, readiness, and commitment rather than prior academic achievement. The application asked students to reflect on their interests, goals, time availability, and relevant experiences to support mentor matching. GPA, prior coursework, and letters of recommendation were not used as selection criteria.

The study collected data during two years in which different students participated in two versions of the same program during the summers of 2024 and 2025. Quantitative data was collected only during 2024. Qualitative data that includes focus groups and final presentations were collected during both years. In total, the program included 17 participants in 2024 and 15 participants in 2025 for a total of 32 participants in this study.

Participants were distributed across four grade levels. Specifically, 27.27% of the students were enrolled in ninth grade, 21.21% were in tenth grade, 33.33% were in eleventh grade, and the remaining 18.18% were enrolled in twelfth grade. Participants also reported their preferred pronouns, which were used to describe gender representation in the sample. The majority of participants (54.55%) reported *she/her* pronouns, followed by 42.42% who reported *he/him* pronouns. One participant (3.03%) reported *they* pronouns.

Methodology

Quantitative data and analytic approach

For quantitative data, pre- and post-surveys measuring attitudes toward CS were administered to participants both before the program began and after it concluded during the 2024 cohort. Both surveys included the same set of questions designed to assess five key constructs related to attitudes toward CS. These constructs and their items were validated by Haynie and Packman [28] and include CS confidence, CS interest, CS sense of belonging, CS usefulness, and CS encouragement. Each construct consisted of five Likert-scale items, with responses ranging from 1 (strongly disagree) to 5 (strongly agree). The original instrument reported acceptable internal consistency [28]. In the present study, minor language adaptations were made to align terminology with the summer research context, which did not affect the reliability of the original survey. Given the small sample size, reliability coefficients were not recalculated, and findings are therefore interpreted as exploratory.

From the 17 participants in the program during 2024, we only analyze data from the eight participants who completed both the pre- and post-surveys. Given the small number of participants, special care was taken to select analytic procedures appropriate for small-sample, within-subject designs. As Field [29] notes, when sample sizes are small, researchers cannot rely on the central limit theorem to assume normality of sampling distributions, making it necessary to evaluate distributional assumptions directly. Accordingly, the normality of pre–post difference scores for each construct was assessed using a combination of skewness, kurtosis, and the Shapiro–Wilk test. Although Field [29] cautions that significance tests of normality have limited power in small samples, he recommends that evidence of non-normality should nevertheless be taken seriously in such contexts rather than ignored. Based on these assessments and following standard and acceptable practices in statistics [29], paired-samples t-tests were used for constructs that approximated normality, as this test is specifically designed for comparing repeated measurements from the same participants. For constructs that did not meet normality assumptions, Wilcoxon Signed Rank tests were employed, consistent with Field's guidance that non-parametric tests are an appropriate and widely used solution for small samples and non-normal distributions in repeated-measures designs. This analytic approach prioritizes alignment between data characteristics and statistical tests, while acknowledging the exploratory nature of findings derived from a small sample.

Qualitative data and analytic approach

The qualitative component of this study drew on two data sources: (1) two semi-structured focus groups conducted with participating students at the conclusion of the program in both years immediately after their final presentations, and (2) students' final project presentations, which included slides documenting project goals, methods, challenges, outcomes, and reflections. The focus groups captured students' shared reflections on their learning processes, mentorship experiences, collaboration, and perceptions of research, while the final presentations functioned as learning artifacts that externalized students' inquiry processes and construction of knowledge through computational work. Together, these data sources provided complementary perspectives on students' engagement with inquiry-based and constructionist learning practices.

The data were analyzed using reflexive thematic analysis as articulated by Braun and Clarke [30]. This approach was selected because it is theoretically flexible, compatible with constructivist epistemologies, and well suited to analyzing both reflective talk and artifact-based data. Analysis followed an iterative, non-linear process. First, researchers engaged in repeated familiarization with the focus group transcript and presentation materials. Coding was guided by concepts from the study's theoretical frameworks (e.g., inquiry practices, learning-through-making, and collaboration) while remaining open to inductively generated insights. Codes were then clustered into candidate themes, which were reviewed and refined to ensure internal coherence and clear distinctions between themes. The codebook was therefore refined during the analytic process. Throughout the process, the researchers adopted a reflexive stance, treating themes as interpretive constructions representing meaning. This analytic approach enabled a theoretically grounded yet flexible examination of how students experienced learning, support, and identity development within the program. Two codebooks were developed. One for answering the first research question (attitudes) and other for the second research question (learning through IBL and constructionism). Both codebooks are presented in Table 1 and Table 2.

Table 1

Codebook for RQ1

Construct	***Codes/guide***
CS Confidence	statements about ability/mastery, overcoming difficulty, "I can do X now," accomplishments, self-efficacy.

CS Interest	enjoyment, curiosity, fascination, future plans in CS.
CS Belonging	peer connection, community participation, feeling known/recognized, comfort collaborating.
CS Usefulness	relevance to real life, cross-disciplinary value, purpose/impact framing.
CS Encouragement	support, access, mentoring, validation, resources, invitations/opportunities.

Table 2
Codebook for RQ2

Theme	**Code**
IBL practices	● Exploration without fixed outcomes ● Reading/using scholarly literature ● Data investigation and interpretation ● Hypotheses revised by evidence / surprise findings ● Communicating methods and conclusions publicly
Constructionist learning	● Building code/models/visualizations ● Iteration/debugging ● Artifact sharing as learning
Supports, participation, identity	● Partner collaboration and peer scaffolding ● Mentor as resource broker ● Distributed mentorship (grad/PhD support) ● Constraints: scheduling/work/time ● Constraints: unclear goals/project mismatch ● Modality preferences (Zoom vs in-person) ● Identity broadening (CS beyond coding) ● Research confidence / reduced intimidation

Findings

RQ1: How does participation in a faculty-mentored, inquiry-driven computer science research program influence high school students' attitudes toward computing?

Quantitative evidence RQ1

Table 3 summarizes the descriptive statistics and pre–post comparisons for participants' attitudes toward computer science across the five measured constructs. Analyses were conducted using matched pre- and post-survey responses from the eight participants who completed both instruments. Mean scores and standard deviations are reported for each construct at both time points. Based on assessments of normality, paired-samples *t* tests were used for CS confidence, CS sense of belonging, and CS usefulness, while Wilcoxon signed-rank tests were used for CS interest and CS encouragement. Statistical significance was evaluated using an alpha level of .05. CS usefulness and CS encouragement are statistically significant. Given the small matched sample (N = 8), statistical significance should be interpreted cautiously. Mean differences suggest moderate practical shifts in CS usefulness and encouragement, but findings are best understood as exploratory indicators rather than estimates of population-level effects.

Table 3
Pre- and Post-Program Differences in Computing Attitudes (N = 8)

Construct	Pre-Test *M* (*SD*)	Post-Test *M* (*SD*)	Statistic	*p*
CS Confidence	21.38 (4.10)	22.13 (3.31)	t(7) = 0.92	.390
CS Interest	24.00 (2.05)	24.13 (1.73)	W = 3.00, z = 0.00	1.000
CS Sense of Belonging	20.13 (3.90)	22.75 (3.10)	t(7) = 2.25	.590
CS Usefulness	21.13 (3.90)	23.50 (2.44)	t(7) = 2.88	**.023***
CS Encouragement	19.00 (3.42)	21.38 (2.88)	W = 36.00, z = 2.55	**.011***

Note. t = paired-samples t test. W = Wilcoxon signed-rank test (used for non-normally distributed constructs). * indicates p < .05.

Qualitative evidence RQ1

CS Confidence

Across data sources (focus groups and artifacts), students demonstrated increased confidence in their ability to engage with computer science practices, particularly those associated with authentic research. In the focus groups, students frequently described learning to do things that initially felt difficult, such as debugging complex code, analyzing unfamiliar datasets, or *"reading a paper,"* which several students identified as a challenging but newly acquired skill. This growing confidence was also evident in the final presentations, where students articulated concrete technical accomplishments. For example, the cryptography team described implementing and understanding encryption algorithms such as AES and Euclid's GCD in Python, framing these achievements as overcoming *"very difficult algorithms."* Similarly, the team evaluating large language models for mathematical reasoning presented a fully functional benchmarking pipeline, discussed trade-offs between accuracy, consistency, and efficiency, and reflected on managing GPU and automation challenges—signals of confidence in engaging with advanced CS tools and practices. Across projects, students positioned themselves as capable problem-solvers who could persist through difficulty, indicating growth in CS self-efficacy.

CS Interest

Students' interest in computer science emerged strongly through expressions of enjoyment, curiosity, and desire to continue engaging with CS topics. During the focus groups, students repeatedly characterized the program as *"really fun"* and *"awesome,"* emphasizing that working on challenging, open-ended problems made the experience engaging rather than discouraging. Several students noted that the program *"opened another door"* to computer science by exposing them to areas beyond what they had previously associated with CS. This interest was reinforced in the presentations through future-oriented statements. For instance, the AI Tetris team expressed interest in extending their work to other games to further explore human-like AI behavior, while the sea-level prediction team outlined plans to study additional environmental factors and conservation strategies. The AI in Education team explicitly described wanting to move from literature review into hands-on prototyping. These forward-looking reflections indicate that students' engagement went beyond task completion and translated into sustained interest in CS topics and applications.

CS Sense of Belonging

A sense of belonging in computer science was primarily constructed through collaboration, peer interaction, and participation in a broader research community. In the focus groups, students emphasized the importance of having partners and teams, describing how collaboration allowed them to *"bounce stuff off each other"* and feel supported when encountering challenges. Students also highlighted the value of program-wide gatherings, noting that meeting others with similar interests in computer science helped them feel more connected and comfortable in CS spaces.

This sense of belonging was also reflected in the presentations, where teams frequently acknowledged peers, mentors, and professors, signaling their participation in a shared community of practice. For example, the AI Tetris team explicitly thanked peers they could *"rely on and talk to"* about their experience, while other teams referenced working closely with graduate students and faculty. Together, these accounts suggest that students did not experience CS as an isolated activity, but rather as a collaborative and socially meaningful endeavor in which they felt they belonged.

CS Usefulness

Students' understanding of the usefulness of computer science broadened significantly through engagement with real-world, interdisciplinary problems. In the focus groups, students explicitly stated that the program helped them see that computer science is *"more than just coding,"* instead functioning as a discipline applicable across domains. This perception was strongly reinforced by the nature of the projects themselves. For example, the sea-level team framed their work as contributing to understanding future coastal impacts, while the mental health and lifestyle data analysis team discussed using CS tools to explore patterns related to stress, exercise, and diet. The AI in Education team positioned computer science as a means to address concrete classroom challenges faced by both students and instructors, and the cryptography team highlighted the everyday relevance of encryption in modern life. Through these experiences, students came to view CS as useful, socially relevant, and connected to issues they cared about, rather than as an abstract or purely technical discipline.

CS Encouragement

Finally, students' attitudes reflected strong experiences of encouragement to pursue computer science, stemming from mentors, peers, and institutional support structures. In the focus groups, students described mentors as providing valuable resources, access to tools, and guidance that they would not have encountered otherwise. Even when mentor availability was limited, students interpreted being pushed toward independent problem-solving as challenging but ultimately encouraging, contributing to feelings of growth and accomplishment. This encouragement was also visible in the presentations' appreciation sections, where nearly all teams explicitly thanked faculty mentors, graduate students, and program organizers for *"giving us a chance to experience this kind of research."* For instance, the LLM benchmarking team acknowledged both a faculty mentor and a PhD student for guidance, while the AI in Education team emphasized collaboration with an entire research group. These expressions reflect students' perceptions that they were supported, valued, and legitimately invited into computer science spaces, reinforcing encouragement as a key attitudinal outcome of the program.

RQ2: What factors influence learning in a computer science program grounded in inquiry-based learning and constructionism?

Qualitative evidence RQ2

Theme 1: Learning Computer Science Through the Inquiry Cycle

Across both data sources (focus groups and final presentations), students consistently described learning as an iterative inquiry process rather than as the completion of predefined tasks. In the focus groups, students emphasized that research allowed exploration without the pressure of achieving a single *"correct"* result, which they contrasted with typical classroom experiences. One student explained that because it was research, *"you don't really have to depend on your results being good, so you could explore more ways to go about the topic."*

This inquiry orientation was also clearly visible in the final presentations. Multiple teams described generating hypotheses, testing them with data or models, and revising their understanding based on unexpected findings. For example, the mental health and lifestyle data analysis team noted that *"some of the data we graphed didn't match what we would have expected,"* explaining that several of their hypotheses *"turned out to not be true"* after analysis.

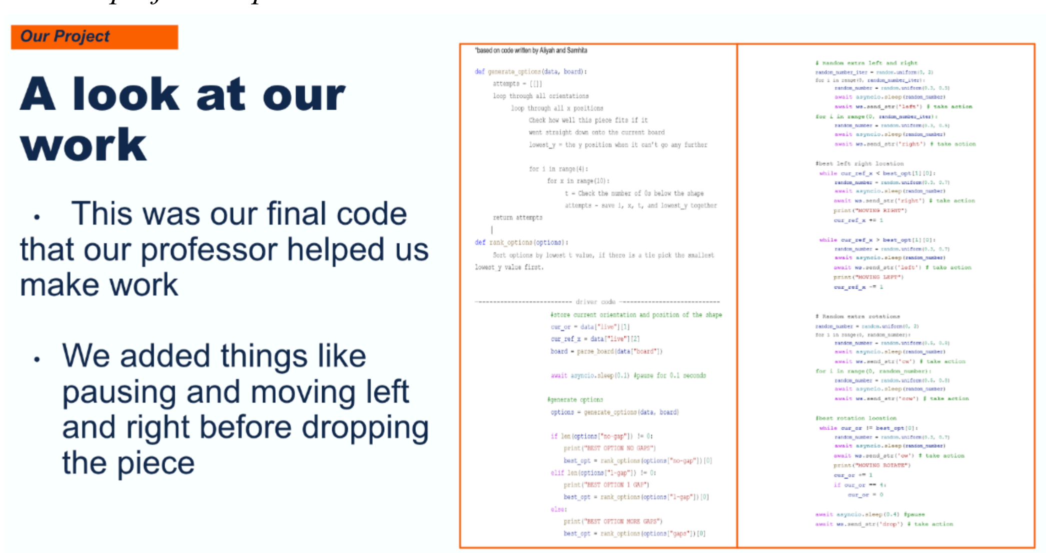
Rather than framing this as failure, students presented these moments as learning opportunities that deepened their understanding of the data.

Similarly, the team evaluating large language models for mathematical reasoning emphasized that benchmarking required evaluating trade-offs beyond accuracy, including consistency and efficiency, concluding that *"there is no single best model"*. These accounts illustrate students' engagement in core inquiry practices—questioning, testing, interpreting evidence, and communicating conclusions—central to inquiry-based learning.

Theme 2: Constructionist Learning Through Computational Artifacts
Students' learning was also strongly mediated by the construction of computational artifacts, which functioned as tangible representations of their thinking and understanding. Across projects, students built code, models, pipelines, and visualizations, and then reflected publicly on these artifacts in their presentations.

For instance, the cryptography team described writing Python functions to implement encryption-related algorithms and learning the mathematical foundations underlying them, including Euclid's GCD and fast exponentiation. The sea level project involved building and comparing machine learning models, including LSTM and linear regression, to generate future predictions based on historical data. The AI Tetris team iteratively modified their code to incorporate "human-like" behaviors such as pausing and lateral movement before dropping pieces, explicitly framing the artifact as a way to model human decision-making (See Figure 1).

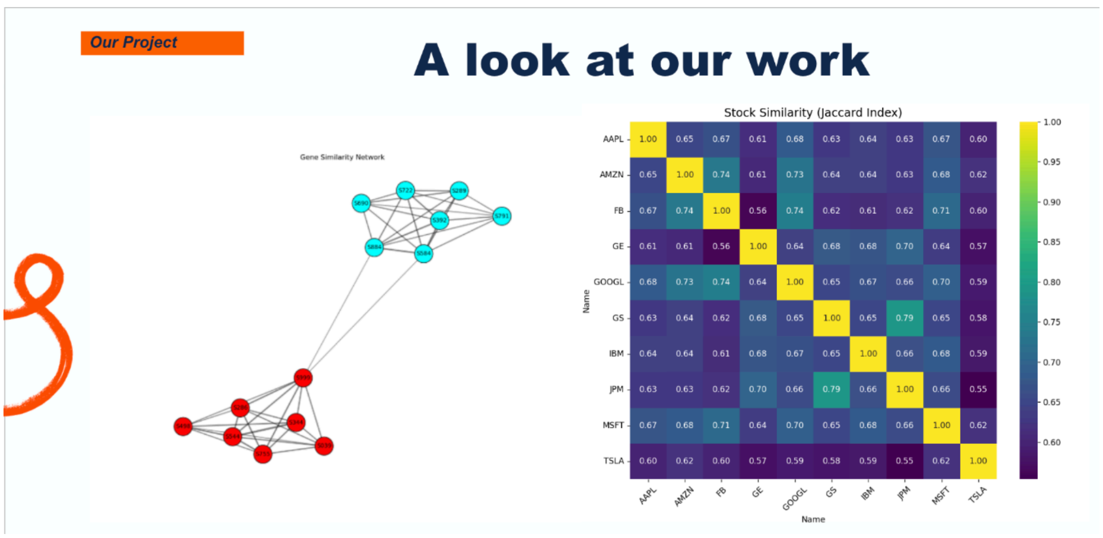
Figure 1
AI tetris project snapshot



Students also emphasized visualization as a key constructionist practice. The Jaccard similarity project highlighted the creation of *"clear and meaningful graphs through Python"* as a major accomplishment, noting that visualization was essential for interpreting and communicating results (See Figure 1). Through these artifacts, learning became shareable and discussable—both within teams and across the program. This was reinforced in the focus groups, where students described learning from seeing others' projects during shared gatherings. One student explained that seeing what other teams were doing allowed them to *"apply that to my project,"* highlighting how shared artifacts supported collective sense-making.

Figure 2

Jaccard similarity project snapshot



Theme 3: Distributed Mentorship and Peer Collaboration as Learning Supports

Students' perceptions revealed that learning was scaffolded through a distributed mentorship structure that extended beyond faculty mentors to include peers, project partners, graduate students, and structured community spaces. In the focus groups, students repeatedly emphasized the importance of having a partner, describing collaboration as a way to *"bounce stuff off each other"* and jointly problem-solve when challenges arose.

Faculty mentors were frequently described as resource brokers who introduced students to new tools, datasets, and ways of thinking. One student highlighted that their professor *"gave me resources that I'd never used before,"* which became a memorable aspect of the experience. Graduate students also played a critical role for some teams, particularly when faculty availability was limited. Students noted that having graduate students available made it easier to get timely help and avoid waiting when they were stuck.

Evidence of this distributed mentorship model also appeared in the presentations, where teams frequently acknowledged not only faculty mentors but also graduate students and peers. For example, the mental health data analysis team explicitly thanked a graduate student alongside their faculty mentor for guidance throughout the project. These findings suggest that learning was supported by a networked mentoring structure rather than a single source.

Theme 4: Productive Struggle Within Authentic Constraints

While students largely described the program as engaging and rewarding, they also articulated significant constraints and challenges characteristic of authentic research experiences. Time limitations, scheduling conflicts, mentor availability, and initial ambiguity in project goals were recurring issues.

In the focus groups, students described frustration when mentors were busy and unable to meet frequently, noting that this sometimes left them to *"figure it out by ourselves,"* which felt challenging in the moment but ultimately rewarding once problems were solved. Scheduling conflicts, particularly for students with work or extracurricular commitments, limited some participants' ability to attend meetings and collaborate fully with their teams.

These constraints were echoed in the presentations. The sea level team explicitly cited time management and the short duration of the program as factors that *"limited how deep the research could go"*. Several teams described grappling with unfamiliar concepts, complex terminology, or large datasets, framing these difficulties as central challenges they had to overcome. Rather than undermining learning, these constraints often contributed to what students described as productive struggle, reinforcing the authenticity of the research experience and fostering independence and problem-solving skills.

Discussion

This study examined how participation in a faculty-mentored, inquiry-driven computer science research program shaped high school students' attitudes toward computing and how students learned computing concepts and practices through authentic research experiences grounded in inquiry-based learning (IBL) and constructionism. Taken together, the qualitative evidence and the exploratory quantitative data suggest that positioning authentic research as a learning methodology—rather than as an enrichment activity—may support students' attitudinal development, engagement with disciplinary practices, and understanding of computer science as an engineering-relevant field.

Participation in this faculty-mentored research program positioned high school students in practices that closely parallel established models of the engineering design process. Across projects, students engaged in problem scoping, information gathering, idea generation, modeling, feasibility analysis, iteration, and public communication—core elements articulated in engineering education research [14]. For example, students working on sea-level prediction constructed and compared machine learning models under real-world constraints, evaluated trade-offs, and revised their approaches based on evidence. These experiences extend beyond learning programming as a technical skill; they engage students in systems thinking, optimization, and decision-making under constraints—hallmarks of engineering design. These findings suggest that faculty-mentored, inquiry-driven research can function as an early engineering design experience, particularly in computing-related domains, by immersing students in authentic problem framing, artifact development, and iterative refinement. Designing research programs that intentionally foreground these practices may therefore provide a viable pathway for broadening participation in engineering by allowing students to experience engineering not as abstract theory, but as socially situated, design-oriented problem solving.

Implications for Students' Attitudes Toward Computing

Quantitatively, statistically significant gains were observed in students' perceptions of CS usefulness and CS encouragement, while other constructs showed positive but non-significant changes. Given the small sample size, these results should be interpreted as exploratory; however, the qualitative findings provide important context for understanding these patterns. Students' narratives consistently reflected expanded views of computer science as socially relevant, interdisciplinary, and connected to real-world problems—an outcome closely aligned with the significant gains in perceived usefulness. Through projects related to sea-level prediction, education, mental health, cryptography, and artificial intelligence, students encountered computing not as an abstract technical skill but as an engineering tool for modeling, analyzing, and addressing complex systems. This framing resonates strongly with engineering education goals that emphasize problem-solving in authentic, real-world contexts [24][25][26][27].

Similarly, gains in CS encouragement are illuminated by students' repeated references to mentorship, access to resources, and being *"invited"* into legitimate research spaces. Faculty mentors, graduate students, peers, and program structures collectively signaled to students that they belonged in computing and engineering pathways. Even when mentorship involved being pushed toward independence, students interpreted this as a form of trust and validation. This suggests that encouragement in computing may not solely stem from constant support, but also from being treated as capable contributors to authentic engineering and research work.

While statistically significant changes were observed only for usefulness and encouragement, the qualitative findings function as explanatory evidence that illuminate how and why attitudinal shifts occurred. Given the small sample size and exploratory nature of the quantitative analysis, the qualitative data are not supplementary but central to understanding how inquiry-based and constructionist research experiences shaped students' perceptions, confidence, and identity development.

The lack of statistically significant changes in CS confidence, interest, and sense of belonging does not imply an absence of impact. Qualitative evidence demonstrated growth in research confidence, persistence through difficulty, enjoyment of open-ended challenges, and strong peer-based belonging. These discrepancies likely reflect both ceiling effects—students entered the program with relatively high interest—and methodological limitations related to sample size and survey completion. Importantly, data suggest that confidence and belonging were constructed through practice and participation over time, aligning more closely with constructivist perspectives than with short-term attitudinal shifts captured through surveys.

Learning Through Inquiry and Construction in Authentic Research

The findings strongly support the integration of IBL and constructionism as a framework for understanding how students learned computing through research. Students' experiences closely mirrored the inquiry cycle described in the theoretical framework: they explored open-ended problems, engaged with scholarly literature, formulated and revised hypotheses, investigated data and models, and communicated conclusions publicly [13]. Crucially, students emphasized that the absence of a single *"right answer"* reduced fear of failure and encouraged exploration—an outcome that contrasts with more rigid instructional environments and reflects core principles of inquiry-based learning. This outcome aligns with Khalaf [4] who highlights the benefits of IBL when compared to traditional instructional approaches.

Constructionism was equally central to students' learning processes. Across projects, computational artifacts—code, models, visualizations, and pipelines—served as learning objects through which students externalized, tested, and refined their thinking. Iteration, debugging, and visualization were not merely technical tasks but mechanisms for sense-making. Public sharing of artifacts in final presentations further reinforced learning by making knowledge concrete, discussable, and socially situated. These practices closely align with both constructionist theory [5][8][9] and engineering education traditions that value learning-through-making, design iteration, and public demonstration of work [20].

The study also highlights the importance of distributed mentorship as a learning support within inquiry and constructionist-based research experiences. Rather than relying on a single dominant instructor, students navigated a network of faculty mentors, graduate students, peers, and community structures. This distributed model reflects authentic engineering research environments and supports constructivist learning by positioning knowledge as co-constructed through interaction [11]. For high-school students, such structures may be particularly important for mitigating challenges associated with open-ended inquiry while preserving student agency.

Productive Struggle and Authentic Constraints

An important implication of this work is that constraints commonly viewed as barriers—limited time, scheduling conflicts, mentor availability, and ambiguous goals—can function as productive features of authentic research experiences if the program is flexible enough. Students frequently described moments of frustration and uncertainty, yet these experiences often led to increased independence, problem-solving skills, and confidence, but those issues were overcome when they developed problem-solving skills and used other available resources such as peers and the distributed mentorship structure. From an engineering education perspective, this mirrors professional practice, where ill-defined problems, trade-offs, and resource constraints are the norm. The findings suggest that carefully designed informal research contexts can allow students to experience productive struggle without the high stakes often present in formal classrooms.
At the same time, these constraints underscore the need for intentional scaffolding. While students ultimately framed challenges positively, uneven mentor access and time limitations sometimes constrained depth of inquiry. This highlights a tension inherent in inquiry-based and constructionist approaches: maintaining openness and authenticity while providing sufficient structure to support novice learners.

Limitations and Future Directions

Several limitations should be considered when interpreting these findings. First, the small sample size—particularly for the quantitative analysis—limits statistical power and generalizability. Only eight participants completed both pre- and post-surveys, which likely contributed to non-significant results for several constructs. Because quantitative analyses included only participants who completed both pre- and post-surveys, results may reflect experiences of students who were more consistently engaged in the program. Second, the study focused on a single program at one site, within an informal summer context, which may differ substantially from formal high school engineering or computing classrooms. Third, data were collected over a relatively short duration (three months), limiting insight into longer-term impacts on students' educational trajectories or persistence in computing and engineering pathways.

Additionally, while the study intentionally foregrounds students' perspectives and artifacts, it does not include systematic measures of conceptual learning gains or comparisons with more traditional instructional approaches. As such, claims about effectiveness should be understood as exploratory and theory-building rather than causal.

Conclusion

Although this study was conducted within a faculty-mentored summer research setting, several structural design features may be adaptable across engineering and computing education contexts. Core elements include positioning open-ended problems as central learning drivers, structuring learning around iterative artifact development, incorporating public presentation of work, and leveraging distributed mentorship models. These features are not inherently dependent on a university laboratory environment and could be adapted within formal high school engineering courses, project-based curricula, or school–university partnerships. At the same time, access to faculty-led research projects and graduate student mentorship reflects contextual affordances of this specific setting. Distinguishing between adaptable pedagogical structures and context-dependent resources may help engineering educators implement inquiry- and constructionist-based research experiences across diverse institutional environments.

Despite the limitations, the study contributes valuable empirical insight into how inquiry-based learning and constructionism can jointly function within authentic computer science research experiences for high school students. For engineering education, the findings suggest that faculty-mentored research—when intentionally designed as a learning methodology—can support both attitudinal development and engagement with core engineering practices. Future work could build on these findings by examining larger and more diverse cohorts, exploring longitudinal outcomes, and investigating how similar models might be adapted within formal engineering and computing curricula.

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