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Knowing and Enjoying: Expanding Latino/a Students' Experiences with an Integrated Computer Science and Mathematics Curriculum

Hakeoung Hannah Lee, Sylvia Celedón-Pattichis, Marios S. Pattichis,
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Abstract

This study explores the relationship Latino/a students developed with Computer Science (CS) and Mathematics while experiencing the Advancing Out-of-School Learning in Mathematics and Engineering (AOLME) curriculum in an after-school setting. Guided by sociocultural perspectives, the authors employed a mixed methods research design to explore how AOLME affects Latino/a students' knowledge and enjoyment of CS and Mathematics (CSM). Findings show that AOLME is a successful example of integrated CSM curriculum design for K-12 learners by balancing the individual and social classroom setting. Quantitative data analysis indicates that students had significant increases in their self-reported enjoyment and knowledge in CS and Mathematics as they engaged in AOLME. Qualitative data provide evidence that AOLME prepared students with the foundational knowledge, skills, and practices for future endeavors in STEM fields.

Keywords

Computer Science Education, Mathematics Education, STEM Education, Computing, Latino/a Students, Middle School, After-school Setting

Introduction

Although the importance and influence of computing in society have grown, paradoxically, the quality of computer science education is losing ground in the U.S. K–12 education system (Wilson et al., 2010). Culturally and linguistically diverse students continue to be underrepresented in Science, Technology, Engineering, and Mathematics (STEM) fields (Bottia et al., 2021; Jong et al., 2020; MacPhee et al., 2013; Riegle-Crumb et al., 2011; Wang & Degol, 2017). Despite initiatives to improve achievement, racial and ethnic minorities (REMs) continue to experience disparities in STEM (Jong et al., 2020). Black and Latino/a students are less likely to persist and graduate in STEM areas than White students (Rincón & Lane, 2017). REMs describe negative STEM experiences that steer them away from these disciplines (Jong et al., 2020). There is an urgent need to expand the number of students from varied cultural and linguistic backgrounds who pursue professions in STEM.

The AOLME curriculum was designed to provide middle school students, especially from underrepresented groups, access to experiences related to STEM knowledge and practices and was revised based on participants' feedback. It integrates fundamental concepts from Computer Science and Mathematics (CSM) needed to represent digital video and color images (LópezLeiva et al., 2017). The goal of the AOLME initiative is to promote middle school students' awareness of both: (a) a set of mathematical practices different from, but still related to the one they have experienced at school; and (b) a set of meaningful experiences in engineering through the processing of digital images and video.

This study explores the relationship that Latino/a students developed with CSM while experiencing the AOLME curriculum. Our main research question for this study is: How is the AOLME curriculum affecting Latino/a students' knowledge and enjoyment of CS and Mathematics?

Literature Review

Results of research in out-of-school learning environments support that these settings play a key role in improving the learning of underserved populations (Ferreira, 2001; McClure &

Rodriguez, 2007). While AOLME also promotes a collaborative team setting, the emphasis is on developing engineering concepts starting from their mathematical foundations and promoting college-level practices (i.e., Linux and basics of object-oriented programming). AOLME also builds on the belief that middle school students should be taught computational thinking in addition to CS and its applications in other disciplines (Grover et al., 2015). Researchers have shown that the middle school years are critical for identity formation and cognitive development for future engagement with STEM fields and for analytical thinking necessary in STEM fields (Grover et al., 2015; Tai et al., 2006). Buitrago-Flórez and colleagues (2017) highlight the need to teach computational thinking through programming as early as elementary school. With respect to teaching novices, the goal is to promote deep learning; however, many students make little progress in the first programming course (Robins et al., 2003).

Theoretical Frameworks

Based on a sociocultural perspective, the AOLME project, as a context, supports students as producers rather than consumers of knowledge (Hourcade et al., 2008; Nugroho & Lonsdale, 2010) and promotes experiences that engage students with engineering traits such as creativity, optimism, collaboration, and communication (National Research Council, 2009). Furthermore, the approach is founded on a participatory, situated, and experiential engineering learning perspective (Berman, 1968; Dewey, 1902; Johri & Olds, 2011; Lave & Wenger, 1991), where the development of engineering and mathematical identities is parallel to a socialized process of learning (Esmonde, 2009; Litzinger et al., 2011; Martin, 2006). AOLME supports a socialization process into engineering by engaging in practices and in a community where students do as, learn about, and become part of, and belong to (Johri & Olds, 2011; Lave & Wenger, 1991; Wenger, 1998) the engineering community. As a context for supporting students' experiences into engineering, we use digital image and video processing and programming as proven rich resources (Douglas, 2001; Karam & Rice, 2000). These resources support the learning and teaching of concepts included in our curriculum, simultaneously integrating computer science, technology, and mathematics.

Methods

Study Context and Data Collection

The Advancing Out-of-School Learning in Mathematics and Engineering (AOLME) program was held at two middle schools in rural and urban areas in the Southwest. All students were on free or reduced lunch.

The curriculum contains two levels. Level 1 introduces the concepts of image and video representations. Level 2 focuses on object-oriented programming. This study focuses on Level 1 implementation of the curriculum, which introduces users to the basics of Linux and Python coding in order to program and represent images and videos down to the pixel level. For this, students learn about the coordinate systems to represent images and videos, and related concepts such as binary and hexadecimal numbers to construct black/white and color images, respectively. The final projects require users to develop their own video representations based on their interests. Activities included pencil-and-paper, modeling, and computer-based tasks using the Python programming language and the Raspberry Pi as a main platform.

Specifically, Level 1 was implemented during the spring semester of each year from 2017 to 2019 in 1.5-hour weekly sessions for a total of 12 sessions. During these sessions, students worked in teams (three to five peers) in which the co-facilitators (i.e., middle school students who participated in the program before) co-taught with an engineering undergraduate facilitator.

The quantitative data corpus for this study includes a total of 67 participants from 2018 and 2019 in Level 1, which was implemented in the same format and modality. The self-reports on CSM practices included two number lines (0–10) for before and after AOLME for students to self-assess their knowledge and enjoyment of CS and Mathematics. The qualitative data for this study included interviews with 12 participants in Level 1—three from a rural school and three from an urban school in 2018; three from a rural school and three from an urban school in 2019. Each group of three consists of the students whose pre- and post-quantitative data revealed the smallest, medium, and largest gains. Individual 1:1 Interviews were conducted for 30-45 minutes at the end of the program. The interview protocol included questions on the students' opinions and thoughts on liking and knowing CS and Mathematics. All names are pseudonyms.

Data Analysis

Taking advantage of both qualitative and quantitative methods, a sequential explanatory mixed methods research design was employed to explore how Latino/a students, after having participated in AOLME, perceived their learning. Incorporating a mixed methods design adds complementarity and triangulation to the study, which enriches findings and strengthens conclusions (Hesse-Biber, 2010). Greene and colleagues (1989) provide development, initiation, and expansion as additional benefits of using mixed methods.

The changes in self-reports of CSM practices separated by liking and knowing were quantitatively analyzed. It was used to determine relationships between and within variables. SPSS Statistics 28.0.0 was used for quantitative analysis. We also used qualitative methods to provide insight into the meaning and reasons for liking and knowing CS and Mathematics. Thematic analysis was used to analyze interviews to describe the students' perception of and relationship toward CSM practices.

Results

Changes in Latino/a students' self-reported enjoyment and knowledge of CS over time using AOLME curriculum

To explore the effect of authentic experiences with the integrated CSM curriculum on Latino/a students' self-reported enjoyment and knowledge of CS, descriptive statistics and paired sample t-tests were conducted to compare the students' level of self-reported enjoyment and knowledge at the beginning and end of the program.

The students had a significant increase in self-reported enjoyment and knowledge of CS (see Table 1). Increases in their self-reported scale over time were evident (see Table 2). The paired sample t-test on the collected data indicated that there is a significant difference in students' self-reports about liking and knowing CS at the beginning and end of the curriculum

implementation ($p < 0.001$). The effect size for the difference between pre-test and post-test enjoyment can be considered large ($d = 1.99$), based on benchmarks suggested by Cohen (1988). The effect size for the pair of pre- and post-test of the self-reported level of knowing CS is also large ($d = 1.99$).

The thematic analysis of the qualitative interview data provided students' reasoning for the change in their perception of CS. Analysis suggested that the AOLME program helped them see CS positively and sparked curiosity to learn more with a transition in perception from, for example, hard or unrelatable to interesting and fun (see Table 3). For example, students' increase in enjoyment was connected to learning new topics and gaining deeper comprehension. Students especially mentioned video creation activity, relating that to their own interests and life, which increased their enjoyment of CS. Furthermore, the AOLME program impacted students' career goals. Qualitative analysis also suggested that students successfully acquired CS knowledge through participating in the AOLME program (see Table 4). Students gained a deeper understanding of CS concepts and developed computational thinking skills in a collaborative learning environment, which played a significant role in terms of the significant increase in liking and knowing CS and Mathematics (see Table 5).

Changes in Latino/a students' self-reported enjoyment and knowledge of Mathematics over time using AOLME curriculum

To explore the effect of authentic experiences with the AOLME curriculum on Latino/a students' self-reported enjoyment and knowledge of Mathematics, descriptive statistics and paired sample t-tests were conducted to compare the students' level of self-reported enjoyment and knowledge at the beginning and end of the program.

The students had a significant increase in self-reported enjoyment and knowledge of Mathematics (see Table 6). Increases in their self-reported scale over time were evident (see Table 7). The paired sample t-test on the collected data indicated that there is a significant difference in students' self-reports about liking and knowing Mathematics at the beginning and

end of the program ($p < 0.001$). The effect size for the difference between pre-test and post-test enjoyment is large ($d = 0.93$). The effect size for the pair of pre- and post-test of the self-reported level of knowing Mathematics is also large ($d = 1.43$).

The thematic analysis of the qualitative interview data provided students' reasoning for the change in their perception of Mathematics (see Table 8). Students enjoyed Mathematics more when they had a deeper comprehension, which increased their confidence in the subject. They liked Mathematics more after recognizing its significance and realizing that what they learned in AOLME improved their mathematics skills. Qualitative analysis of interviews suggested that students successfully acquired mathematical knowledge through participation in the AOLME program (see Table 9). Furthermore, students gained confidence as they learned more. They learned how Mathematics could be connected to real life and even described their struggles while acquiring new knowledge. Students understood the connections between CS and Mathematics (see Table 10). Also, students mentioned that their enjoyment of Mathematics was connected to that of CS.

Discussion and Implications

Analysis of quantitative data indicated that students had significant increases in their self-report of enjoyment and knowledge in CS and Mathematics as they engaged in the AOLME curriculum. Qualitative data provide evidence that AOLME prepared students with the foundational knowledge, skills, and practices for future endeavors in STEM fields. Specifically, a video-making project comprised sophisticated and artistic works, and students were attracted to it, producing unique and creative variations. AOLME serves as a successful example of integrated CSM curriculum design for K-12 learners by balancing the individual and social classroom setting.

Students previously had restricted and discrete views of Computer Science and Mathematics. However, their views shifted significantly to a sophisticated understanding of CSM as a problem-solving discipline where programming can be used to make people's lives easier, entertaining, creative, and engaging. Students found that code is "language" (p. 214) and

“grounded mathematics” (Burke, 2016, p. 213), understanding the relationship between CS and mathematics. Students have gone through the process of discovering the relevance of CS and mathematics in their own life and reported mastery of core disciplinary ideas in a manner conducive to their application in future endeavors. Having that experience, students connected CSM to their future careers.

The system of people, CSM practices, technologies, and values in the after-school programs provided opportunities for learning in-depth and thinking creatively for the students (Barron, 2004). Students brought rich sets of “funds of knowledge” about homes, communities, personal interests, peer interactions, and prior experiences in school (Moll et al., 1992), which led to significant increases in their liking and knowing CS and Mathematics. Bilingual environments heightened the need for cooperation, and the authentic and collaborative learning environment of AOLME provided students with rich educational opportunities (LópezLeiva et al., 2022). Students used technological tools and materials as a means to express themselves.

This study concludes that AOLME successfully created bridges to future learning. The synergies created by teaching Mathematics through CS education and vice versa, which were bridged by shared aspects of procedural thinking and problem-solving, provide evidence that an integrated CSM curriculum successfully fosters STEM learning. Although AOLME embodies a learning theory-informed, pedagogically designed curriculum, it still has room for improvement. Future directions involve overcoming the limitations of this study to create a robust curriculum shown to work in diverse settings and with broader audiences nationally and globally.

Tables

Table 1

Descriptive Statistics for Students' Self-Report about Liking and Knowing Computer Science

			N	M	SD
Pair 1	Enjoyment	Pre-test	67	5.08	2.46
		Post-test	67	8.88	1.49
Pair 2	Knowledge	Pre-test	67	3.03	2.63
		Post-test	67	7.82	1.78

Maximum value is 10; minimum value is 0.

Note. For enjoyment, students (N=67) reported an average score of 5.08 (SD=2.46) which represents a significant improvement to an average score of 8.88 (SD=1.49). For knowledge, students (N=67) reported an average score of 3.03 (SD=2.63) which represents a significant improvement to an average score of 7.82 (SD=1.78).

Table 2

Paired Sample t-test Results for Students' Self-Report about Liking and Knowing Computer Science

		M	SD	Std. Error Mean	t	df	Sig	Effect Size
Pair 1	Enjoyment (Post-test - Pre-test)	3.81	1.91	0.23	16.29	66	0.000***	1.99
Pair 2	Knowledge (Post-test - Pre-test)	4.79	2.40	0.29	16.32	66	0.000***	1.99

Significance calculated using a two tailed t-test; *** p < 0.001, ** p < 0.01, * p < 0.05

Effect size calculated using Cohen's d.

Table 3

Changes in Students' Enjoyment of Computer Science

Context	Example
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Students were enthusiastic about learning new topics and realizing their own ideas.	Jeremias: It's interesting and fun, that's what I think. Interviewer: Interesting and fun. Why interesting? Why fun? Jeremias: Interesting because you're learning something way different that you never used to do. [Interviewer nods head] Like, using codes that I never used before and fun because you create your own image, however you want. [Interviewer nods head]
	Eric: Everything is fun, .. all at the beginning .. what I used to learn, the computer parts, that was fun. Everything is fun. Right now, it's fun too, like we are working on that project.
	Julio: Well, now I can make videos which I couldn't make before, cause [before,] I only knew how to make video games. And can make images, but of course I can't make them round. Let's say my finger. Because it's all in pixels unless you did one of those ninety billion by ninety billion grids which would actually make a curve. Because the squares are so small that you can put a thousand of them and it would look curved... I like my experience. It was fun and I got to do something I liked which was programming. So, it was cool I thought.
	Victoria: Oh, and last week, before I left, I was really happy because I learned how to... We were doing a Minecraft scene, and I figured out how to make a body of water without... Because before that, we were doing it, but there was a little border around it and I didn't want that. I figured it out how to make the squares.
Students enjoyed Computer Science more when they had a deeper comprehension.	Jesus: I learned a lot more about computer programming ... hexadecimal and . binary all that stuff. So, I learned a lot more about it, and I had fun doing it. With the group and stuff, that was really fun too. So I wanted to try to learn a little bit more ... It's because I just understand it better now. Interviewer: I see. So you feel like the more you understand the more you like it? Jesus: Yeah, cause it gets easier.
Students enjoyed Computer Science more when they experienced a sense of self-efficacy by helping peers.	Juanita: Yeah, I think that ... it made me proud to know that I made someone understand the topic more ... So when helping here, I felt kind of happy because I was... I knew that I was able to help them with the stuff they struggled with, and here I got really happy because I ... I got to get a challenge with facing different people that I don't know what they know yet.
Students' confidence in	Julia: ... I just kind of freaked out whenever it was a new code. And now I'm like "Oh, hey! A new code. Let's try it out."

Computer Science grew.	
Students enjoyed Computer Science more after recognizing its significance and experiencing its excitement through CS projects.	Jenny: Before I didn't really think computer programming could do anything for me. I just thought, "Hey I could just do whatever I want, I don't need computer programming. But now I realize there are a lot of things that come with computer programming, and how important it is... Also, it was really fun too. When we were making the little pixel and the video. That's what I really liked about it. That it had a lot of fun things to do.
	Julio: I like making the characters or like that video because they look cool when they're on a freaking screen and they like [making gestures in air] boom, boom and then move around like Mario. We can make a tree or even the ground. We can make blocks. We can make a bunch of stuff. Like an alien or something.
Students liked Computer Science more when they learned that technology could help them express themselves.	Samantha: I like them because I could show how I feel about myself in a computer and feel about what others feel on what they do. Interviewer: Are you showing something that you feel in the video that you're doing? Samantha: Yeah. Interviewer: What are you showing about yourselves? Samantha: We are going to show about a sloth hiding in a bush and they are going to scare our group. Interviewer: Oh. So why is that connected to you? Samantha: Because I like that something is going to scare us but something is going to be fine.
Students described how the AOLME program impacted their career goals.	Herminio: Well, at first I've been realizing that future careers are gonna require programming. Gonna be the future language like a future language. Jose Antonio took me to these physicists over there at the labs and so, they started talking and they told me that it was nice that I was into physics but also into programming like for experiments like something hasn't been created, so, they have to program it. [That influenced me to change my career goals] because as a physicist I thought it was just numbers and all that, but now I realize it is more like languaging. Like, programming language that you can use and so if something hasn't been created you're gonna have to create it. And I like that.
	Juanita: In the future, I want to be a part of a big business company. So I am pretty sure we are gonna need a lot of coding to have the stuff ready and everything.
	Mauricio: Oh what got me interested was really anything. I used to look at a show or a video game. I used to [think] like; how do they

	program all of this. And then I looked up programming and found the app. Then, I started making little figures. Like little men... So I think after AOLME, when I get my PC, or the computer, I'm gonna do computer coding on that because on my iPad, it just, watch. [Mauricio writes] That's my [career] path... I'm just going to start coding on my computer, and create little images or animations. And I'll just go from there with my path.
	Jenny: [In the future I will be] helping others understand how to code and how important it is... And using the math to make more code and make new things and create other websites or new things like animations or something.

Table 4

Students' Knowledge Gain in Computer Science

Context	Example
Students described their understanding of hexadecimal number systems.	Victoria: [R, G, B is connected to the colors] but in the hexadecimal, you don't put RGB, you put the hexadecimal codes for... So, there's ... 0 is white, I think so. And then, there's like a, b, and you have to put 2 in order to be a pair, I mean you could put 1 to change the color slightly. Interviewer: You need to put pairs for what? Victoria: Pairs for RBG. Because they each have their own but it's not actually... Interviewer: So, you need a pair of hex for R and a pair for B and a pair for G? Victoria: Yes, and it's all six digits and whenever you're done putting it, you could apply it to... refresh it and it will get the new picture.
Students described their understanding of image and video creation.	Julio: [In the video we made,] right now we have a call of duty person and then we have a Minecraft slime who is red and is [making air gestures to demonstrate] basically sort of like a cube but with the edge or the corners cut off. And then we have a call of duty guy who's right there next to him and the slime is supposed to jump up and eat the person. Interviewer: How do you do that? Julio: Well, we have to use different frames. A frame is the picture or the image. And you have to keep changing it that way it looks like the one thing is moving or something so it goes like [demonstrates with hands]. Well, to create a frame you have to copy the first frame but instead of frame zero, let's say you put

	frame one it's going to be the next one. So, then you change the codes just slightly a little bit that way it looks like they're moving... That way it can make the full images. If you only use one code, it's only going to make one part of the character. So, like their foot or something. Mauricio: [In AOLME,] I learned that numbers can actually mean colors. Like one, one, one zero, like zero is black and one is white. And then like 000000FF, the rest are F. I think that's red. And I was like, "How do numbers create colors?" Like they're just plain numbers. And then it, so then I didn't think it was possible at the time I came, [which is] before AOLME. And then when I was a [AOLME] student, I looked at the colors and I'm like, "How are these color-coded?" And I went through the code and I saw a bunch of numbers, and I asked the co-facilitator, "What are these numbers doing?" And they're like, "those are the colors" and I'm like, "what! How the, how in the french toast are these colors? They're just numbers, plain numbers!" And then she, and then my co-facilitator was, "some numbers can equal, some numbers can equal a color like zero is black, one is white" and then, she wasn't, I don't remember if it was a she or a he but my co-facilitator was explaining to me how other colors could lead to other numbers like 0000FFFF could equal black, red. And then I was like, "that's pretty cool". How math can go into colors and programming. And then it creates an image.
Students described how their comprehension of Computer Science has advanced over time.	Victoria: [Before,] I didn't know almost anything about computers. I mean, I've heard of it, but I didn't know what it was... [but now] I feel like I definitely learned all about computer programming from AOLME ... I thought, "Wow, maybe I should learn about it." I just feel like I definitely learned. I didn't even know RGB and the hexadecimal were a thing. ... I knew what pixels were, but I didn't know what their use was. Now, I know. ... I knew that it was things like smartphones, computers. Basically, anything with a smart voice, anything that can complete a task for you. Like searching up Youtube, you know? The computer could do that task for you and bring up youtube and then, you could watch videos and it will play it for you. I thought it (Computer Science) was that, but now I know it's not... Computer programming is like... Let's say I have a robot and I want to control it but I didn't know how. I would have to learn computer programming because I have to program a computer to control it.

	Jenny: All I knew about computer programming before is that it had ones and zeros and that's all I knew. Now I know it involves hexadecimal code, binary, it does have ones and zeros, and it takes a lot of math and patience to do like a little simple video to do.
	Lucia: ... because at this time (before AOLME) I didn't know a lot of stuff and on this side, after, I started to understand more things by knowing the details perfectly.
Students developed computational thinking skills.	Samantha: I thought computer programming was just programs about how to program a computer on just putting numbers and know instructions... [I learned] that if you don't put any instructions, it's just going to do whatever it wants to. And it has to be in a correct order... Because if you put something that it's not on its place it's going to do a different thing and then it's going to not come out like you were planning.
	Herminio: It (AOLME) helped me think on math... Because students in our school... I think they don't get coding stuff. So, they think differently from what I think. I think in if it were like a code or like a process... [AOLME helped me at] my algebra class. I've been taking it and it's all in computer. So, you have to be paying attention or you're just gonna miss out on something. I think it helped me to understand the process... You're using a process of math. How to get a polynomial or something like that. So, I think almost as a programmer. So, I'll say okay... So, this is the first step to finding this and, then, this would be your output from what you put into your input. That's your input.

Table 5

Collaborative Environment Affecting Students' Liking and Knowing Computer Science and Mathematics

Context	Example
Collaborative learning environment affecting students' knowledge gain.	Juanita: Yeah, I think that .. it made me proud to know that I made someone understand the topic more ... When helping here, I felt kind of happy because I was... I knew that I was able to help them with the stuff they struggled with, and here I got really happy because I got to get a challenge with facing different people that I don't know what they know yet... I had like other

	girls that were older than me, they helped me a lot understand it when I was struggling, same with my sister.
	Hermínio: Well, because they start participating more and they start answering questions that were difficult and they started expressing themselves ... Everybody here helped me start getting it, understanding it ... Whenever you know something and then you teach it to somebody else that would tell me I understand it.
	Bryan: (I feel) better, since I actually explain to people. I actually thought I wouldn't be able to talk. Actually, I explained them pretty well ... Last time I just saw the code and copied it and pasted it. Now you have to actually explain the code and I actually learn more about it how it works and that. And, now, I actually do.
	Eric: Cause in AOLME, they (peers) make me understand better. People are helping me. At my school, the teacher .. doesn't really help. He is just, does the math on the board and tells us to do this page and stuff like that and then he goes sits down on his desk and we have to do it. So I don't really get it.
	Jesus: So we were all learning the stuff together. And we helped each other with our learning, some of us were kind in groups ... And we were made we each understood it so that we could help understand the new people here.
Collaborative learning environment affecting students' enjoyment.	Julia: I actually think that it's super fun because I actually get to teach people the things that sometimes I didn't get too easily. I could teach them in more simple ways ... When we did the converting decimal into binary then binary into hexadecimal, I already knew that (Unintelligible.) then, I did it really fast. Then, I could actually help them (Unintelligible.) I actually help them if they made a mistake kind of... So, add them up and see how many have left and go like that. It's a really easy way ... AOLME makes I can understand it better.
	Mauricio: So binary numbers, I love binary numbers. I love binary numbers because they're cool, even though I said how I don't like numbers. But binary numbers explain a lot. Like how you, like a block can equal a lot of other blocks. Like how on the TV, when you go close to it, it just looks like a big frame. It looks like a big frame, but when you go close to it, you will see red, blue, green. And a bunch of other little pixels ... What I kind of think is cool with binary numbers is, you know that white

	paper? Where it has the one square, 2, 2 square and all that. How it has that (Inaudible) thing? Interviewer: That table? Mauricio: Yeah. But what was interesting is that Quino showed me a pattern. Like look, 10101010 and so on, so on. And then 11001100. And then 111000111 I think. Yeah. And then [counts in head]. So look, so it has 1010101. You see that pattern right? 1,0, and then 11001100 and then it does it two times. 1,1. And then 1, 2, 3, 1, 2, 3, and then 1, 2, and so on. And then 1, 2, 3, 4, 1, 2, 3, 4. Quino showed me that and I was like, “That’s crazy! You should have told me that so I wouldn’t have to do all those freaking numbers.”... He showed me that pattern and then that made things really easy. Like easier.
	Juanita: I was worried exactly about the math in the computer programming but what like the way that my sister helped me finding fun for it, I worked hard to understand it. And luckily I was able to understand it the way they would show me here in AOLME, that ... that’s how I thought it’s funner ... Before, I wasn’t putting much effort in mathematics because I hadn’t thought that I would be able to do it. So [in AOLME] I wanted to put a lot of effort. [Before,] I would feel like I would get it wrong. So I wouldn’t try to do it. [Now,] I think that I should try to do it because if I don’t try it, then I don’t know it’s right or wrong.

Table 6

Descriptive Statistics for Students’ Self-Report about Liking and Knowing Mathematics

			N	M	SD
Pair 1	Enjoyment	Pre-test	67	5.75	2.99
		Post-test	67	7.94	2.49
Pair 2	Knowledge	Pre-test	67	5.90	2.31
		Post-test	67	8.29	1.83

Maximum value is 10; minimum value is 0.

Note. For enjoyment, students (N=67) reported an average score of 5.75 (SD=2.99) which represents a significant improvement to an average score of 7.94 (SD=2.49). For knowledge, students (N=67) reported an average score of 5.90 (SD=2.31) which represents a significant improvement to an average score of 8.29 (SD=1.83).

Table 7*Paired Sample t-test Results for Students' Self-Report about Liking and Knowing Mathematics*

		M	SD	Std. Error Mean	t	df	Sig	Effect Size
Pair 1	Enjoyment (Post-test - Pre-test)	2.19	2.35	0.29	7.62	66	0.000***	0.93
Pair 2	Knowledge (Post-test - Pre-test)	2.40	1.68	0.21	11.67	66	0.000***	1.43

Significance calculated using a two-tailed t-test; *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

Effect size calculated using Cohen's d.

Table 8*Changes in Students' Enjoyment of Mathematics*

Context	Example
Students enjoyed Mathematics more when they had a deeper comprehension, which increased their confidence in the subject.	Julia: Because right now... Like I told you, I was really bad at math. Then, after I joined programming with all the codes and the binary, hexadecimal and everything, it kind of helped me understand a lot better. To be better at math, because most of the things I learned, I could actually kind of apply them in math to make it kind of easier. ... I noticed that I'm doing a lot better in everything. I get almost perfect grades in my homework because of all the programming things and... Interviewer: Can you give an example about... Julia: So, in one of the texts of (Unintelligible), there was actually a problem where you have to solve 10 to the power of 4. So, now, I can easily do it without getting confused about what I'm supposed to do and doing it wrong. So, I answered the question right because everything I learned here, I applied to the text.
	Victoria: This was recently. We learned how to use the pixels from our first frame, and in our first frame, it will only go up to 17 and a half even though for the ... Which it kind of also helped me learn the coordinate plane which we were learning in class but I knew a little more because of AOLME and also ... I don't

	know how to word this but, definitely, I felt kind of more, a little bit stronger at math.
	Juanita: I have always wanted to do a lot of stuff with computers. But only problem was that I didn't like math and computer has to do with math. So, I just didn't want to do the math part because I didn't like math ... When I get it (Math) better and know more that's when I started wanting to do it more ... What I think that started to help me understand math more were kinda like hexadecimal was that kind of part of core that like you had to put in. And I think that was very helpful for me ... I didn't give the math a chance to realize and since they started showing me more what it was about, that's what got me really interested in it.
	Lucia: Binary. Let's see... Let's go with two to the power of two, two to the power of three. At first, you, being a student, you were learning each time. So, you were so confused. You were like "Whaaaat?" ... So, then, when I went to this step, it feels like "Oh! I'm getting there. I think I have a shot to do this. I think I'm going to succeed and get to the top so I can know everything well and show another kid." There you go. [Passes paper to Interviewer] ... You know things like two plus two equals four, right. You know those things. You know how to subtract, how to divide, how to multiply. But when you keep on going throughout the time, you learn exponents, you learn binary, you learn colors, and many things that work out from that way until you learn what you have actually. You start by two plus two equals four, two times three equals six, but throughout the time each time you go from the first day. You know this stuff. Second day, you learn the exponents. You start learning each time more and more ahead until you get, "Ohh now I get it. Pew pew." [Does celebration noises with mouth.] It actually helps you more when you go throughout because you start from this point and you want to go to the top because you want to learn what is going on. [Talks while writing on paper.] Each time you go from the first, second, third, and fourth. Until, in the fifth, you are on top and you get it. You start... you actually have everything more easy for you. Pew pew! [Simulates more noises and flips paper.] Samantha: It was not that interesting. But after this, I started getting better on math on understanding it ... I am doing better in math

	in school after AOLME because now I know how grids could work on a number line without whole numbers. ... I feel that I could learn more in math and I could be advanced ... That I could do more numbers that I could turn them into something else.
	Julio: Well, I like it now more because I'm understanding how to do the coordinates like this [drawing on paper]. You can say ten, ten it's going to make a little thing right there [shows the paper to Interviewer] [Interviewer agrees]. So, I wasn't good at coordinates before but now I started doing AOLME and then I got good at it.
Students enjoyed Mathematics more after recognizing its significance and realizing what they had learned in AOLME improved their math skills.	Jenny: Well, when I was in math, I didn't really like math that much, but I did it and I liked it because my friends would do math with me and stuff. And now I like it more because now I know that doing math is really important for binary and stuff. For even coding and other things too... It helped me with math [in school] because we were starting to get into exponents.
	Bryan: [Being in AOLME helped me like math more] because you know, the stuff we learn, the binaries, and then the hexadecimal. It actually helped me at math.
	Samantha: Because in fifth grade I used to not be very good at math because I couldn't express how something could change in math. After this, I went to this program and I went to growing about my math skills ... I know how to put a variable and change it ... I have, I've known math better than I was last year.
Students described how they liked math more when they looked at things from different points of view.	Lucia: By learning different perspectives you learn different things, you know how to make a smiley face by starting with the math, or maybe the student did eyes and then the math. Now, you do it differently but there's always two ways and you can come back to one or you can come back to another one. By that, you can explain your students this is how we start and this makes it easier. If not, you can do this method and it makes it easier. So Seeing it in different ways makes it like more.

Table 9

Students' Knowledge Gain in Mathematics

Context	Example
Students described their understanding of the AOLME curriculum contents.	Mauricio: I learned how to do the column and the row. Because when I was a student, I didn't understand the rows and columns. And how it had like numbers next to it. Like a 12 and I looked at the frame, like the square. And it had 12 and 12 and I was like, "Isn't that the same number on rows and columns?" And he was like, "Yeah because that's, that, that 12 is what gets the square that big". I was like, "Oh! That's why it says rows and columns because rows and columns". And then they're both 12 and the 12 next to the rows and columns is, yeah basically, so, I learned rows and columns and...
	Julio: So the numbers obviously have something to do with math but you also have to use them with the Y and X and Y axis so the X is up and the Y is this way [points left] and you have to put it on the grid. So, let's say I want zero, three. So, I have to put it on the three, since it's zero. So, just on the three. And then that makes like one little square and then one, three; two, three. And then that makes a whole rectangle.
Students learned how Mathematics could be connected to real life.	Herminio: I've always liked math but now that I've entered the AOLME program, I've learned new ways on how it's used, and today's modern world, it's something useful. And I realized, I really never knew you could use math on something like this.
Students gained confidence through acquiring more knowledge.	Jenny: When I go to AOLME and learn some new stuff, I tell my friends at school and they're like [surprised], "I do not understand". Then when I go back I under-, I get more knowledge, and then when I go back to school, everybody is like [Surprised], "How do you know all of this?" I even, I try very hard to explain to them...
Students described their struggles while acquiring new knowledge.	Juanita: I learned really paying attention and I worked how I struggled with math. So, I had a hard time learning it. ... Well, it means something different to me cause like since it's getting into a higher grade level, we are learning more different stuff, and it's struggling but it's getting there. Interviewer: It's getting there? Juanita: And from AOLME, it's getting there, I am getting there either way.

Table 10

Students' Showing Understanding of Connections Between Mathematics and Computer Science

Context	Example
Students described the connection between Computer Science and Mathematics.	Jesus: They (Computer Science and Mathematics) are connected. I just like computer programming better.... It's.. loops is like multiplication you could say. Instead of adding number by itself again and again, you can just multiply it by how many times you wanted to add it. And then you could do that ... we use the loops to do stuff multiple times to get it done faster and to use less blocks, as we are using blocks of codes.
	Mauricio: Isn't the coding kind of like geometry, timesing the width times the height and all that? Interviewer: So you're thinking about it like geometry? Mauricio: I'm thinking about it like geometry is kinda similar to programming because it has a geometry square. Like this. [Mauricio writes.] Like this. It has a little square. And then you know how you do height, width, and all that? Base. Interviewer: Right. Mauricio: Well, numbers like, let's just do it on the number 6, 7, 5. And then on certain, it depends on the shape. It really depends on the shape. Like you could do that and then just any kind of shape. Really, but it depends, yeah really it depends on the shape, so on some shapes you do length times width, height times base and then base times width I think. And then how we could do, since we're doing, since height times width is like 6 times 7. 6 times 7 equals... Interviewer: So you're thinking of these as frames? Or how? Mauricio: I'm thinking of it like, do you know how in the frame were the colors, it has a little square ... the little pixel. I'm kinda thinking of a pixel like the square. And then if we put like 0000FFFF, it would change this cube to a color like red or something. Like that. Interviewer: Okay. Mauricio: Because it's just a plain square. It's just white but then if you put a code inside it, 0000FFFF, it adds... it's colored. Like red or a blue code and then a million more colors... That could go inside the cube.
	Samantha: Because I thought it (math) was only going to be on just writing numbers and letters but after this I know you can do something with the computer programming and make an action. Make a thing out of it.
Students explained their enjoyment of	Juanita: It (Math) used to be interesting but it got funner for me (due to AOLME).

Mathematics and Computer Science are related.	Interviewer: Why did it get funner? Juanita: Because since it had to do with programming, and since it had to do with math, I thought it was pretty fun. ... it's like we use computers, and we were learning math in there Computer programming would be like .. it has to do a lot with codes and math. So it's practically doing math, just that you are doing it in a computer, for like most people would be a funner version.
	Mauricio: [School is] just sitting down and seeing a grown person showing you numbers. And homework is the worst thing that could happen. I hate homework. But then when I came to AOLME, I saw that AOLME had some like all the numbers. Just all the numbers to math and I was like, "did math create programming?" Because since we use, let's see, since we use 1, 0, we use probably like a five for the frame and the columns. I was like, "(inaudible) so cool have numbers in it?" And I was like, "maybe math created programming since it has, it has a lot of numbers". Because, since, what me and my group are doing right now we're doing a code thing where a DVD is moving, and there is like 500 frames which is straight up numbers ... Yeah so, it's a lot of numbers.

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References

- Barron, B. (2004). Learning ecologies for technological fluency: Gender and experience differences. *Journal of Educational Computing Research*, 31(1), 1-36.
- Berman, L.M. (1968). *New priorities in the curriculum*. Charles E. Merrill Books.
- Bottia, M. C., Mickelson, R. A., Jamil, C., Moniz, K., & Barry, L. (2021). Factors associated with college STEM participation of racially minoritized students: A synthesis of research. *Review of Educational Research*, 91(4), 614-648.
- Buitrago Flórez, F., Casallas, R., Hernández, M., Reyes, A., Restrepo, S., & Danies, G. (2017). Changing a generation's way of thinking: Teaching computational thinking through programming. *Review of Educational Research*, 87(4), 834-860.
- Burke, Q. (2016). Mind the metaphor: Charting the rhetoric about introductory programming in K-12 schools. *On the Horizon*, 24, 210–220. <https://doi.org/10.1108/OTH-03-2016-0010>.

- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*, 2nd ed. Hillsdale, NJ: Erlbaum.
- Dewey, J. (1902). *The child and the curriculum*. The University of Chicago Press.
- Douglas, S. (2001). *The Infinity Project: DSP and Digital Music in high school Eng. Education, IEEE Workshop on Applications of Signal Processing to Audio and Acoustics*.
- Esmonde, I. (2009). Ideas and Identities: Supporting equity in cooperative mathematics learning. *Review of Educational Research*, 79(2) 1008-1043.
- Ferreira, M. M. (2001). The effect of an after-school program addressing the gender and minority achievement gaps in science, mathematics, and engineering. *ERS spectrum*, 19(2), 11-18.
- Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a conceptual framework for mixed-method evaluation designs. *Educational evaluation and policy analysis*, 11(3), 255-274.
- Grover, S., Pea, R., & Cooper, S. (2015). Designing for deeper learning in a blended computer science course for middle school students. *Computer science education*, 25(2), 199-237.
- Hesse-Biber, S. N. (2010). *Mixed Methods Research: Merging Theory with Practice*. United Kingdom: Guilford Publications.
- Hourcade, J. P., Beitler, D., Cormenzana, F., & Flores, P. (2008). Early OLPC experiences in a rural Uruguayan school. In *CHI'08 extended abstracts on Human factors in computing systems* (pp. 2503-2512).
- Jong, C., Priddie, C., Roberts, T., & Museus, S. D. (2020). Race-related factors in STEM: a review of research on educational experiences and outcomes for racial and ethnic minorities. *Handbook of research on STEM education*, 278-288.

- Johri, A., & Olds, B. M. (2011). Situated engineering learning: Bridging engineering education research and the learning sciences. *Journal of Engineering Education*, 100(1), 151–185.
- Karam, L., & Rice, D. (2000). Teaching Image Processing to high-school students: A web-based, active learning approach in teaching image processing to high school students is presented. SPE 2000 Workshop.
- Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.
- Litzinger, T., Hadgraft, R., Lattuca, L., & Newstetter, W. (2011). Engineering education and the development of expertise. *Journal of Engineering Education*, 100(1), 123–150.
- LópezLeiva, C., Celedón-Pattichis, S., Pattichis, M. S., & Morales Flores, J. (2017). Teaching and learning number systems for computational thinking: Underrepresented students accessing high-quality STEM practices. In A. Fernandes, S. Crespo, & M. Civil (Eds.), *Access and equity: Promoting high-quality mathematics in grades 6-8* (pp. 89-103). Reston, VA: National Council of Teachers of Mathematics.
- LópezLeiva, C., Noriega, G., Celedón-Pattichis, S., & Pattichis, M.S. (2022). From students to cofacilitators: Latinx students' experiences in mathematics and computer programming. *Teachers College Record*, 124(5), 146-165.
- Martin, D. (2006). Mathematics learning and participation as racialized forms of experience: African American parents speak on the struggle for mathematics literacy. *Mathematical Thinking and Learning*, 8(3), 197-229.
- MacPhee, D., Farro, S., & Canetto, S. S. (2013). Academic self-efficacy and performance of underrepresented STEM majors: Gender, ethnic, and social class patterns. *Analyses of Social Issues and Public Policy*, 13(1), 347-369.

- McClure, P., & Rodriguez, A. (2007). *Factors related to advanced course-taking patterns, persistence in STEM, and the role of out-of-school time programs: A literature review*. New York, NY: The Coalition for Science After School.
- Moll, L. C., Amanti, C., Neff, D., & Gonzalez, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory into practice*, 31(2), 132-141.
- National Research Council. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. National Academies Press.
- Nugroho, D., & Lonsdale, M. (2010). *Evaluation of OLPC Programs globally: a literature review*. Camberwell, VIC, Australia: Australian Council for Educational Research.
- Riegle-Crumb, C., Moore, C., & Ramos-Wada, A. (2011). Who wants to have a career in science or math? Exploring adolescents' future aspirations by gender and race/ethnicity. *Science Education*, 95(3), 458-476.
- Rincón, B. E., & Lane, T. B. (2017). Latin@s in science, technology, engineering, and mathematics (STEM) at the intersections. *Equity & Excellence in Education*, 50(2), 182-195.
- Robins, A., Rountree, J., & Rountree, N. (2003). Learning and teaching programming: A review and discussion. *Computer science education*, 13(2), 137-172.
- Tai, R. H., Qi Liu, C., Maltese, A. V., & Fan, X. (2006). Planning early for careers in science. *Science*, 312(5777), 1143-1144.
- Wang, M. T., & Degol, J. L. (2017). Gender gap in science, technology, engineering, and mathematics (STEM): Current knowledge, implications for practice, policy, and future directions. *Educational psychology review*, 29(1), 119-140.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge University Press.

Wilson, C., Sudol, L. A., Stephenson, C., & Stehlik, M. (2010). *Running on Empty: The Failure to Teach K--12 Computer Science in the Digital Age*. ACM.
<https://doi.org/10.1145/3414583>