2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #37208

Understanding Pre-service Teachers Perspectives on STEM and Robotics in Early Childhood Classroom (ECE) Integration: A Critical Feminism Perspective

Yinqi (Anna) Zhang, Penn State University

Yinqi (Anna) Zhang is a third-year Ph.D. student in Educational Psychology. Her/their research focuses on quantitative methods, STEM education for preservice teachers, and incorporating Feminist theories in applied settings in Education and Psychology.

Brian Belland, Penn State University

Understanding Pre-service Teachers Perspectives on STEM and Robotics Classroom Integration: A Critical Feminism Perspective

Anna Yinqi Zhang
Pennsylvania State University

Brian R. Belland, PhD
Pennsylvania State University

'I'm really big into gender equality… women's rights' — informant

Introduction

The underrepresentation of girls and women in Science, Technology, Engineering, Mathematics (STEM) has been a long-standing concern for many [1], [2]. Despite a tremendous increase in women's college enrollment, men continue to outnumber women in STEM fields, and by graduation, men outnumber women in nearly every Engineering and Science major and the difference in majors like Engineering, Computer Science is drastic [3]. Furthermore, girls and women did not retain their STEM majors [1], [4]. The effort of promoting STEM and robotics education should start with early childhood education (ECE) for many reasons: reducing negative gender stereotypes [5], encouraging women and other marginalized groups' participation in STEM, achieving social justice purposes [6], etc. In this paper, we examine preservice teachers' perception of STEM and robotics integration in ECE. The authors' epistemological, theoretical, and methodological foundation of this research was informed by the Critical Feminism.

Literature Review

Critical Feminist Theory

Critical Feminism is an ever-evolving and malleable theoretical framework [7]. Critical Feminism, as an epistemology, methodology, and method, investigates the relationship between knowledge production and power structures, questions the dominant ideology, and aims to emancipate and encourage ambivalence, ambiguity, and multiplicity instead of imposing structures and order [8]. Traditional epistemology and assumptions claim the voice of science to be masculine and systematically exclude the possibility that women can be knowers [9]. Pretending any (social) science to be gender-neutral, misrepresenting gender, and/or omitting the discussion of 'gender, social contexts, and meanings' is not power-neutral but rather power-justifying by legitimating individualism and conservatism and allowing the racist and sexist status quo to prevail [10]. Even though the conventional sciences claim to be objective and value-neutral, they have grievously failed marginalized groups such as women, people of color, and working-class people - only to name a few - resulting in further gender inequalities compounded by racial/ethnic inequalities and ultimately the exclusion of women in power from society [10]. The 'truth' can be complicit in capitalist and colonial pursuits [10], [11], [12]. What counts as theories in the dominant community do not necessarily serve, if not harm, the marginalized communities.

Critical Feminism in STEM Education

The underrepresentation of women and girls in STEM has been and is still a long-standing concern for many [1], [2], a phenomenon explored by a few from a Critical Feminist lens. Kinzie [1] reflected on their personally discouraging experience with science in college and theorized to understand inequities in women's participation with four pathways: 'nevers,' 'departers,' 'joiners,' and 'persisters.' [13] examined STEM mentoring programs in their meta-analysis using a Critical Feminist approach. Gender, oppression/patriarchy, challenges within institutions, and systemic challenges were identified as obstacles for girls and women in STEM and the authors critiqued STEM mentoring programs failed to address concerns for individuals who do not fit into the binary gender category and the intersectional oppressions. There are many cases where the authors apply a Critical Feminist lens without explicitly stating such commitment. For example, informed by the typology of student resistance and work on intersectionality, Rodriguez et al. [6] explored how Latina undergraduate students critiqued racist, sexist, and classist structures of their STEM undergraduate education and how they engaged in community transformation and healing. Supporting women and other minorities' participation in STEM has implications for social justice. Similarly, valuing the lived experience of Black women in STEM demonstrates our commitment to move beyond the rhetoric of resting the responsibility of coping and adaptation solely on the individual levels [14]. Still, research that explicitly has a Critical Feminism commitment is wanting. Our work aims to fill such gaps, disrupt the mainstream discourse, and highlight the agency and intellectual contribution of our predominantly female preservice teachers.

STEM and Robotics Integration in ECE

Participating in robotic activities was an engaging and rewarding experience for students of both genders [15]. Sullivan and Bers [5] found that kindergarten students, regardless of gender, were equally successful in their mastery of introductory robotics and programming. Preschoolers enjoyed playing in the ScratchJr environment and developed fundamental programming constructs and computational thinking [16]. Robotic manipulatives facilitate children's understanding of abstract ideas in a less complex and fun way and engagement in collaborative learning and teamwork [15]. Children actualize their metacognitive and logical thinking abilities during their interactions with computers [17]. The instant and constructive feedback feature of some educational robotics allows for the emergence of situational awareness and decision-making, resulting in a fuller scope of critical thinking abilities even in a chaotic environment [18].

The effort of promoting STEM must start in ECE and continue through secondary education, higher education, and the workplace. Integrating STEM and robotics in ECE allows girls to foster a STEM identity from early childhood and those who do face fewer obstacles entering the field [19]. Children as young as 4-7 years old start to form ideas about which engineering and technology activities and materials are more suited for which gender [19]. Negative stereotypes can lower girls' aspiration to have a science or engineering career while a growth mindset fosters their interest and achievement in math and science, which is critical for women to persist in STEM [1], [3].

Students' choice of STEM disciplines and courses is heavily influenced by their teachers and parents and they are more likely to engage in STEM activities if they have had engaging experiences of STEM activities in their classrooms [20]. As 'the success or failure of the STEM movement will depend on the acceptance and buy-in that schools and teachers give to the integration of these four disciplines in an already crowded curriculum' [21], both preservice and in-service teachers play an important role in incorporating the STEM content and robotic units in early childhood curriculum.

Challenges of STEM and Robotics Integration

It is not without challenges to prepare teachers, both pre-service and inservice alike, with no STEM interest or STEM exposure to teach STEM and robotics in their classrooms. The majority of teachers are not yet fully prepared to incorporate robotics in their teaching [22]. Papadakis and Kalogiannakis [23] found that, although preschool teachers hold a positive attitude towards educational robotics, they lack relevant knowledge. This is sometimes attributed to preservice teachers' lack of exposure to teaching with robotics in both their preservice and inservice time

[24]. Other limiting factors identified include teachers' pedagogical beliefs, beliefs about themselves, and beliefs about technology in integrating technology into the K-12 curriculum [25], [26]. According to Margot & Kettler [27], while PreK-12 teachers valued STEM education, they reported challenges on the structural and institutional level, pedagogy, assessment, and concerns over students.

Yet such challenges can be overcome. Research has shown that preservice teachers benefit from improved STEM engagement, especially emotional engagement, after participating in the robotics unit in a teacher preparation course [28]. Practice integrating technology-relevant activities using robots boosted participants' confidence and knowledge (of teaching practice, safety, and ethical issues) and their likelihood of incorporating more technology in future classrooms [24]. Hands-on professional development workshop (e.g., working with LEGO and learning about STEM 'Big Ideas' lessons) help teachers build technological, pedagogical and content knowledge and foster their confidence in implementing robotics-based STEM activities in classrooms [29].

Research Question

Limited research has been done addressing preservice teachers who receive training in robotics and STEM education and understand their thoughts and feelings about STEM and robotics integration in their own classrooms, not to mention one from a critical Feminist perspective. We, along with our informants, intended to address the following research question from a Critical Feminist Perspective:

RQ: What are preservice teachers' perceptions of the benefits, barriers and concerns (both structural level and individual level), and recommendations for pedagogical practice for STEM and robotics integration in ECE?

Method

As one's methodology of research flows with their epistemology, reflecting and clarifying our backgrounds, epistemic goals, and commitments naturally became the very first thing to do in the Method section, followed by detailed information on informant recruitment and their engagement with robots and lesson design in the teacher preparation courses.

Positionalities and Rejection of Neutrality

The first author was born and raised in an East Asian country before moving to the United States to pursue a college degree in STEM and moved on to a graduate degree in Educational Psychology. The first author uses 'they/she' pronouns. The studies from which the interview came are part of a grant to the second author, which focused on helping preservice, early childhood teachers learn to debug block-based programming so they can teach with robots. Through the project, we developed scaffolding to help these preservice teachers learn to debug, and researched the effectiveness of such [30], [31], [32], [33]. But one of the critical take-aways from this research was the importance of the positionality of the informants as prospective teachers who were learning to teach early learners, women who are highly under-represented in computer science and engineering, and potential role models for early learners who are just beginning to explore computer science and engineering. The first author was very interested in exploring this intersectionality, and thus was formed the genus of this paper.

Instead of taking a God-like perspective, we believe that researchers and practitioners are historically and socioculturally placed and thus the knowledge generated is socioculturally situated and not value-free [9], [34]. The authors were mindful of the impact their upbringing and education training have on the sense-making process. Acknowledging that they were by no means value-free, the we invited the informants to co-construct the process. We would like to emphasize the ultimate goal, rooted in the Critical Feminist tradition, is to understand preservice teachers' perspectives on STEM and robotics integration in ECE and potentially encourage the participation of the historically underrepresented population in STEM. Hence, we believe that preservice teachers' testimonials are a valid source of knowledge [35] and here is the commitment to 'studying ourselves and studying up' [9].

Reflexivity
For Critical Feminist researchers, self-reflexivity is another key component in the sense-making process [36]. We have been constantly reflecting on questions such as 'For whom we are speaking? What is the nature of our interaction? How do we present our work? To whom do we present our work?' and every single word of this piece was carefully crafted while we made sense of my own feelings, thoughts, and reflections throughout the process. For example, as we read more about preservice teachers' experiences and envisions, we were amazed by their creativity: many chose to use robotics to teach English Language Arts and Social Science subjects.

Ethnography-Inspired Method
The piece is heavily inspired by the ethnography method, which connotes our intention to engage in open and honest conversions with, and more importantly, *learn* from our *informants*. We hesitated to call them 'participants' as these preservice teachers interviewed were more than participants (whom I study passively) to us. Rather, they are 'informants' and teachers to us [37]. We hesitated to call the interview responses 'data' and we have adopted the term 'stories.' We understood that 'doing interviews is a *privilege* granted us, not a right we have' [38] and truly grateful for our informants throughout the process. Interview is both a process and a product. We want to be reflective, performative, and critical and to speak from a collective point of view 'women' as opposed to 'woman.'

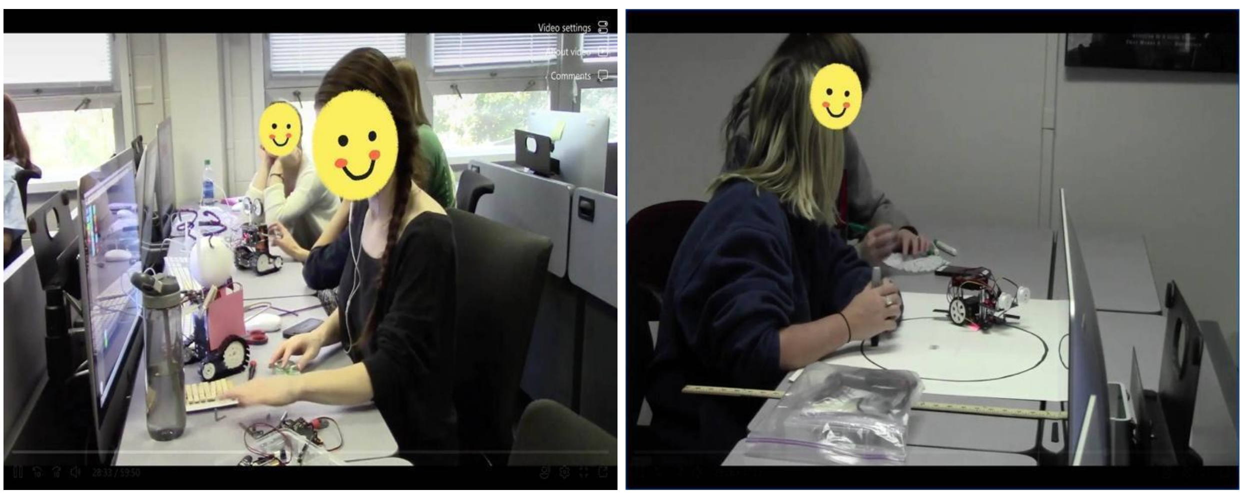
Lastly, we recognize the *intersubjectivity* and the social construction of knowledge via discourses; knowledge construction is through language and that 'the medium of the discourse is language, which is neither objective or subjective, but intersubjective' [39]. The Feminist perspective heavily influenced our reading and interpretation of the interviews. The piece is written *by, about, and for women* [40] and aims to let informants' genuine thoughts and emotions unfold naturally.

Interview Stories
The interview stories were collected during interviews in six studies, where the context for each study was a unique section of the same preservice teacher education course in a large public university in the Southeast United States. Each section was offered in a unique semester. Informants were recruited under a protocol approved by the IRB of the large public university in the Southeast United States. To recruit informants, a researcher visited the classes, explained the purpose of the study – to learn how preservice teachers learn to use robotics technology in K-12 classrooms from videos, lesson plans, and discussions. Informants in all six studies participated in a robotic unit during their teacher preparation course, designed a lesson plan incorporating robots, and completed approximately 30-minute structured interviews. In the interviews,

informants were invited to reflect on their processes of: (a) robot design, (b) robot assembly, (c) robot programming, and (d) lesson design, as well as on the challenges they faced and how such were overcome, and what they learned about STEM learning and teaching. As we used an interview guide approach in which broad categories of interview questions along with specific interview questions are specified before conducting the interview, but allowance can be made for tailoring questions to probe deeper into areas of interest [41]. The six study cohorts share many same or similar interview questions. There was a lot of room for clarification and elaboration from the informants' side. The interview audio was transcribed on a specialized online platform.

Informants

All 76 informants gave consent to participate in the study. We have the demographic information of 75 informants. Among them, 96% self-identified as female, and 4% self-identified as male. The racial composition is 6.67% Asian, 5.33% Latinx, 2.67% Black, 81.33% White, and 4% of other races. Student ages ranged from 19 to 55 years old, with a mean of 20.5 years old and a median of 20.00 years old. On average, the informants have completed 45.24 credit hours. In the interviews, the majority of our informants expressed that they were new to programming and that the opportunity of participating in the study was their first time seeing and working with a robot.



Activity Pictures from Robotic Units

Our informants are mostly preservice teachers who are women and not majoring in any STEM field. We reject outright the assumption that female learners who do not major in STEM or do not teach STEM and robotics content in their early childhood classroom have resulted from the 'deficiency' of being women. Rather, it is a problem complicated by institutional and structural factors to a greater extent. We examined the issue of gender inequity by identifying barriers for preservice teachers on a structural level and envisioning ways to empower them and other future female and other marginalized educators.

Understanding the Stories

The first author identified all themes and categories in informants' responses by thoroughly reviewing their interview stories from all six cohorts. The reviewing process took four rounds. The second author reviewed the themes, categories, and interview samples coded.

In the first round - meaning condensation [39], the first author highlighted each informant's relevant responses relevant to our research question and created a document either paraphrasing or quoting informants' responses. Special attention was given to informants' responses on STEM and robotics learning and teaching (e.g., how to integrate STEM and robotics content and implement classroom activities, what are some perceived benefits and barriers, etc.).

In the second round - meaning generation, the first author thoroughly went over the informants' interview stories again and revised the document created in the first round. The first author had a good picture of all the major themes and categories in mind by the end of this round of re-analyzing interview responses and revising the document.

In the third round, the first author went back to the interview and compared it with the documented information again. Then, in a separate Excel file, they recorded the presence of each theme and category and attached each informant's interview responses in each theme marked present. If the category was reflected in the informant's response, the author marked the presence as '+1' and '0' otherwise. This process allowed them to quantify how many times in total a category was mentioned by all informants. The purpose of reviewing each interview three times in great detail was to uncover all the possible themes and categories and offer a holistic picture of the informants' perspective.

In the fourth round, the first author returned to the interview transcripts and the file documenting the relevant interview responses (in the first few rounds) and revised the coding to ensure that they had captured all the relevant story snippets. They compared the coded texts in this round with the selected texts in the third round and marked any discrepancies in red.

As the end goal is to have a rich description of the informants' perspective, hence there is a moral obligation concerning how they write. Reporting is the process where the authors hope to bring people together. Following Kvale's [39] guidelines, when the authors reported the analysis result in the next section, they contextualized and interpreted the quotes while making them relevant to the general writing. The authors rendered the conversations into a readable, written text format, and the maximum length of the interview quotes is no more than half a page. Only the most essential quotes are presented. 'How to dialogically engage in reading and writing and make the piece reader-ly?' was a concern while they were writing up the piece. The goal is never to generalize the stories. Everything we look at here is not definitive, and thus the interview and the reporting of it has become an event, a performance.

Results and Discussion

We identified the three major themes and categories across all interviews. The three themes identified are perceived benefits of STEM and robotic integration, perceived barriers of STEM and robotic integration, and recommended practices from preservice perspectives. We presented the findings discovered by how often they have been addressed by our informants in Table I, Table II, and Table III. Next, we highlighted some insights from our preservice teachers and their alignment (and/or misalignment) with a Critical Feminist perspective.

Table I. Perceived benefits of STEM and robotics integration in ECE

n = 66	Early exposure to STEM and robotics builds a solid knowledge foundation for all students.

n = 60	The robotic activities can increase students' motivation and engagement, because they are fun, engaging, and have brought students joy and interest.
n = 27	Early exposure to STEM and robotics can break gender norms in these male-dominated fields.
n = 26	Robotic activities are beneficial to the development of higher-order cognitive skills (e.g., problem-solving and creativity).
n = 24	Exposure to robotics and STEM in ECE informs future career choices (for both boys and girls).
n = 23	The robotic activities are hands-on and beneficial to students' motor skills development.
n = 6	Students learn teamwork and communication skills from working on robotic activities.
n = 6	The robotic activities can grab students' attention.

Table II. Perceived barriers of STEM and robotics integration in ECE

n = 53	Age appropriateness of having robots in early childhood classrooms.
n = 35	Time constraints in the classroom, standards and grading, and difficulty in robotic integration.
n = 18	Lack of funding, resources, and other forms of support from local schools and school districts.
n = 17	Motivation concern (e.g., students have no interest in STEM and robotics, frustration, non-participation).
n = 9	Students who have physical and mental disabilities, resulting in an inability to understand the STEM and robotics instructional material.
n = 2	Lack of parental support.

Table III. 'Best' pedagogical practice of integrating robots and STEM in ECE

n = 29	Teachers need to be considerate, patient, and creative.
n = 25	Having students work in pairs or small groups and good classroom management is necessary for successful STEM and robotics integration.
n = 24	Teachers should break down the task into small steps and build it up step-by-step and slowly. Clear instructions are helpful.
n = 23	Teachers should partially or fully put together robots for students in ECE.

n = 7	Teachers need to be proponents of STEM and give special attention to students' motivation.

Perceived Benefit: Building a Solid Knowledge Foundation for All

Many believed that early exposure to STEM and robotics content helped students develop a foundational knowledge base and understand the importance of STEM. Some informants commented that once the student had built the foundation, they could keep advancing their knowledge by various means as they proceeded on their education journey. Robots have been shown to be successful and flexible in different STEM learning scenarios at all educational levels [42], play a conducive role in STEM subjects learning, have the potential to mitigate a lack of interest in STEM subjects in school [43]. Empirical evidence has shown that even in the subject area of spatial skills where male learners consistently outperform female learners, a simple training course can improve an individual's spatial skills dramatically, indicating that a course as such can drastically increase female learners' ability, confidence, and the possibility to have a career in STEM [3]. A corollary is that an early exposure to STEM for learners of all kinds may motivate them to learn more about the subjects of interest and stay in the field.

Perceived Benefit: Encouraging Female Students' Participation in STEM

Many informants who self-identified as women realized that robots and STEM were not as challenging as they thought to be and would love to integrate them into their classrooms. Many also commented that exposing young girls to STEM and robotics was beneficial as the curriculum was eye-opening and would give these students a sense of accomplishment and control. These preservice teachers were very intentional when it came to how they designed their lessons and robots (e.g., creating robots that looked like ducks and princesses) as well as how they named their robots (e.g., using female names) to attract more females to the STEM field. Participation in robotic programs has a positive impact on young girls' perception of their abilities and attitude toward engineering [44]. The gender gap between male and female learners can be reduced by robot-assisted instructions and learning platforms suitable for both genders and keeping the learning flow [45].

*'Just building up that confidence and showing them [girls] that it can be fun, and exciting, and that **they can do it**, and that **they can do it just as well as the boys**…'*

Perceived Benefit: Learning about Teamwork from Working Together

A few informants mentioned that students can learn about teamwork from working together with robots. Robots have been implemented in after-school programs to promote learning by doing and teamwork [46]. Robotic program fostered problem-solving in a team setting through generation and sharing new ideas, co-construction of knowledge, and other socio-cognitive processes [47].

The perceived benefit aligns well with the Feminist pedagogy, as collaborative learning with robotics has the potential of transforming classroom learning into a liberatory environment where student-student, student-teacher, teacher-student interactions act as subjects instead of objects [48], disrupting the power dynamics in traditional classrooms.

*'I think they get **communication benefits** because they will be able to work together, and communicate their ideas.'*

*'If you put kids together in a group, you can learn **cooperation** and **trial and error**.'*

Other Perceived Benefits: Improving Motor Skills, Attention, Cognitive Abilities and Motivation and Engagement; Informing Future Career Choices for Both Girls and Boys

The hands-on characteristic of robotic activities is beneficial to students' active learning. Use of educational robots in classrooms effectively grab students' attention, as teachers' lecturing is much more monotonous compared to having students work with robots under proper guidance. Mere lecturing can lead to passive learning whereas robotic units can foster an active learning environment. In such an environment, the educators' role is to offer opportunities for young learners to engage in hands-on exploration and construct knowledge in the classroom environment [49]. Furthermore, engaging with robotics has implications for learners' cognitive and metacognitive development such as mastery of subject content, research skills, problem-solving, decision-making, and creative thinking [50]. 26 informants reported that doing robotic activities would be beneficial to develop higher-order cognitive skills such as critical thinking (e.g., relational skills) and creativity.

Many of the above-perceived benefits of robots-integrated classrooms parallel those in a feminist classroom where students integrate the skills of critical thinking and the ability to work with others with respect. Here, we can see our informants' emphasis on critical thinking and creativity. Critical thinking should not be perceived as an abstract analysis but as a reflective process grounded in everyday experiences, questioning embedded assumptions and making them explicit through dialogues [48]. In an active learning environment, the informants reject traditional teachers' roles as authoritative figures and appreciate their students' autonomy, creativity, and intellectual contributions to the classrooms.

Perceived Barriers (Institutional/Social Level): Lack of Funding and Resources; Time, State Standards, and Evaluation Concern; Lack of Parental Support

Lack of funding and resources needed can deter pre-service and in-service teachers from integrating robots into their classrooms. Many in-service teachers believed the lack of funding and physical infrastructure hinder the application of educational robots in both primary and secondary education and have called for school funding to support the development of robotic projects [51]. The enormous amount of class preparation time could deter some teachers from using robots in their classrooms. Many informants commented that, on top of the financial cost involved with robots, it had taken a lot of time for themselves as adult learners to assemble and program these robots, so it would probably take more time for an elementary school student to finish the robotic tasks.

As educational standards are statements about the purposes, priorities, and goals for education at certain grade levels [52], it is not difficult to see how state standards have dictated the ways teachers structure and carry out their curriculum. Some informants mentioned that as there was no standard on robotics, which meant that students probably would not get tested on robotics and activities as such took away valuable instructional time of other subjects students will be tested on. The lack of evaluation metrics resulted in difficulty in grading and evaluating students' performance in robotics.

The lack of parental support (e.g., parents' non-involvement or whose lack of the money to purchase a robot for their kids) were also perceived as a barrier by two informants to robotic implementation in their classrooms. Young users, parents, and teachers all need to be on board to ensure the success of educational robot programs. These perceived barriers can all deter preservice teachers from using robots in their classrooms.

Perceived Barriers (Student-Level): Age Appropriateness, Ability, and Motivation Concerns

A majority (n = 53) of the informants expressed concerns about the age appropriateness of robotic activities in ECE. For example, some younger students do not know how to use screwdrivers to put small pieces of robots together or some students may not understand the point of robot assembly. Some informants had reasonable doubts that robotics activities could be challenging for kids who had short attention spans and who had physical or mental disabilities (e.g., students who have strokes or who are rated lower on the intellectual scale).

On one hand, informants' stories have informed us that integrating STEM and robotics in early childhood education is never a one-size-fits-all approach: some of our informants put a lot of effort into lesson design and instructions for both students who are already interested in and motivated by robots and for those who have not yet developed such interests for various reasons. On the other hand, it is our hope to make educational robots accessible for everyone, especially for students with disabilities.

Recommended Pedagogical Practice: Teachers Should Be Considerate, Patient, and Creative

Some informants designed lesson plans with *Frozen* and *Angry Bird* themes. Researchers need to recognize that integrating STEM and robotics content in teachers' curricula may not be as simple and intuitive as it appears and will require conscious and consistent efforts on their side, which should be very much appreciated. At first sight, such connections may seem naive and further reify the gendered nature of STEM. But it is a critical first step for our informants to think about robotic integration in their classroom and make the robotic experience relevant for their students. We understand that how our informants experience and understand things around them is deeply rooted in their everyday experiences and social positions (a presumption in Critical Feminist theory): some believe that using Angry-Birds- and Frozen-themed robots can effectively spark girls' interest and inspire them to work with robots and that is partially why they made such pedagogical decisions.

Different students have diverse interests so not every single student will be interested in STEM. Having robots in the classroom should be viewed as one of the many learning options (instead of the only option) and can help students discover where their interests lie. Following this line of reasoning, some informants recommend making robotic activities optional (e.g., using robots for recess activities or after-school programs) and modifying the robot activities every time to keep students constantly interested and engaged. The emphasis on 'choice' once again aligns well with our Critical Feminist orientation: we respect students' choices once they have been exposed to and learned about educational robots and from there, students can choose their own journey with it.

'As a teacher, I would probably understand the ***skill level*** *that the kids will be able to have… We are* ***not pushing them too hard****'*

*'****Frozen-themed*** *and* ***Angry Bird-themed****, to me, is something that the kids would like… that would be something that's very* ***relatable*** *for them.'*

'Different kids like different things… I think I would even get kids an ***option*** *like if* ***we have in door recess****, you can get the robotics and you can work on it. You can keep it together and next time we have been recessed you can continue to work on it… Then [students] may be getting the option to go back* ***after school*** *or during* ***play time*** *or free time and* ***choose*** *which they feel most into or excited about.'*

Recommended Pedagogical Practice: Having Students Work in Pairs or Small Groups
Feminist pedagogy is concerned with building community within the classroom and believes that the learning occurs through constructive dialogues and relationships [53]. Growing a sense of community and care is central to the Critical Feminist pedagogy, which can be partially achieved by having students work in pairs or small groups and building a warm and inclusive classroom environment. Working in pairs or groups shortens the amount of time to complete tasks and potentially reduces stress on the teachers' side. Interaction among peers involves an exchange of viewpoints, strategies, and skills, which can lead to self-reflection and self-regulation of one's own practice [54]. Furthermore, collaborative learning can lead to active and creative learning. Learners create new knowledge when they share common goals and solve problems together and socio-cognitive conflicts positively influence one's structuring and verbalization of knowledge [54].

*'It is a lot easier to **pair up**, because I know if I had to do it by myself, it would have taken a lot longer than actually did. And pairing up, many **creative minds** can be put more into what they will be able to do with their robot.'*

Other Recommended Pedagogical Practices
The three other recommended pedagogical practices include fully or partially putting together robots for students, breaking down the robotic task into small steps, and being proponents of STEM and motivating their students. All three recommendations exemplify the learner-centered approach, which has connections with other existing learning theories such as critical pedagogy and feminist pedagogy [50]. This represents our critical attempt to theorize motivation from a women-centered perspective with multiple flexible, learner-centered approaches to promote equitable STEM education. Hence, there is an outright rejection of the banking concept of education and an emphasis on autonomy as well as intellectual contributions of our informants and their students.

Having teachers partially or fully build the robots or using assembly-free educational robots can relieve teachers' stress yet still expose young learners to the idea of technology and class content and foster their interest, self-efficacy, and motivation. Teachers, though not necessarily having to be experts in STEM and robotics, need to be proponents of STEM for their students and motivate their engagement, especially girl learners, in subject areas they have never been exposed to. Examples our informants mentioned were to help their students see the importance of STEM (task-value), encourage their participation, and have teachers themselves being proponents of it. It is only through teacher encouragement and open-ended tasks that becomes possible an active participatory culture that fosters students' interest and creativity in educational robotics [55]. When given age-appropriate technologies, children engaged with education robots and even took their first step in developing technological fluency and computational thinking [56].

*'It might be okay to **show them already made and programmed**, and give a little intro to it. But probably not the best for actually building it and programming it.'*

*'It would be cool if we worked with a program online for girls who could not code, like **an hour of code everyday**… Little stuff like that I could incorporate in class.'*

*'I think they [teachers] should be **motivated** by it, I don't think they have to be experts at it necessarily… They have to be **proponents** of it, and be like "engineering is really important and you can do this!" and "math is really important, you can do this!"'*

Conclusion

Our informants' responses have indeed shed light on some of the best critical feminist pedagogical practices to integrate robots and STEM in ECE. The informants highlighted many pedagogical practices beneficial to the development of students' creativity and critical thinking, with the potential of transforming their classrooms into an inclusive and collaborative environment for all as well as social justice purposes. We noted that, however, half of the perceived barriers were on the structural or institutional level: the districts and schools lacking funding and necessary resources for STEM and robots, parents may not necessarily be supportive of robot integration, and teachers need to teach according to state standards and the testing/evaluation are already stressful for them. At the moment, much of the responsibilities are still on the shoulders of both preservice and in-service teachers. Structural and institutional barriers are still present and can potentially deter ECE teachers from implementing STEM and robotics content in their classrooms.

Then the question remains: How can we shift the burden? From a Critical Feminist perspective, we learn from listening to and giving voice to our informants, understanding their intentions and where they lead us to, and embracing their actual life stories. Through self-reflection, we gauge how we can do better to support both preservice and in-service teachers to integrate STEM and robots into their daily curricula.

Recommendations for Future Research

We call for support for preservice and in-service teachers that is sustainable and does not rely on continuous grants. One way of support would be helping preservice and in-service teachers see how robotic activities can be connected to existing curricula and standards and how they can be used to facilitate the teaching of relevant subjects instead of adding another to-do item on their already packed lesson plan. With these goals in mind, we call for researchers and practitioners alike to create a more equitable and inclusive learning environment for all.

Acknowledgements

This research was partially supported by the National Science Foundation (NSF) under grant 1906059. Any opinions, findings, and or conclusions are those of the authors and do not necessarily represent official viewpoints of NSF. The funder has no role in the design or conduct of the study.

References

[1] Kinzie, J. (2007). Women's paths in science: A critical feminist analysis. *New Directions for Institutional Research, 2007*(133), 81-93.

[2] Thom, M. (2001). *Balancing the Equation: Where Are Women and Girls in Science, Engineering and Technology?*. National Council for Research on Women, 11 Hanover Square, 20th Floor, New York, NY 10005.

[3] Hill, C., Corbett, C., & St Rose, A. (2010). *Why so few? Women in science, technology, engineering, and mathematics.* American Association of University Women. 1111 Sixteenth Street NW, Washington, DC 20036.

[4] Fouad, N. A., Hackett, G., Smith, P. L., Kantamneni, N., Fitzpatrick, M., Haag, S., & Spencer, D. (2010). Barriers and supports for continuing in mathematics and science: Gender and educational level differences. *Journal of Vocational Behavior, 77*(3), 361-373.

[5] Sullivan, A., & Bers, M. U. (2013). Gender differences in kindergarteners' robotics and programming achievement. *International journal of technology and design education, 23*, 691-702.

[6] Rodriguez, S. L., Bukoski, B. E., Cunningham, K. J., & Jones, A. (2020). Critiquing oppression and desiring social justice: How undergraduate Latina students in STEM engage in acts of resistance. *Journal of Women and Gender in Higher Education, 13*(3), 251-267.

[7] de Saxe, J. G. (2014). What's Critical Feminism doing in a field like Teacher Education?. *Multidisciplinary Journal of Gender Studies, 3*(3), 530-555.

[8] Lather, P. (1991). *Getting smart: Feminist research and pedagogy within/in the postmodern.* Routledge.

[9] Harding, S. (1987). Is there a feminist method. *Feminism and methodology, 26*.

[10] Fine, M., & Gordon, S. M. (1989). Feminist transformations of/despite psychology. In *Gender and thought: Psychological perspectives* (pp. 146-174). Springer, New York, NY.

[11] Nielsen, J. M. (Ed.). (2019). *Feminist research methods: Exemplary readings in the social sciences.* Routledge.

[12] Winfield, A. G. (2012). Resuscitating bad science: Eugenics past and present.

[13] Beck, M., Cadwell, J., Kern, A., Wu, K., Dickerson, M., & Howard, M. (2022). Critical feminist analysis of STEM mentoring programs: A meta‐synthesis of the existing literature. *Gender, Work & Organization, 29*(1), 167-187.

[14] Morton, T. R., & Nkrumah, T. (2021). A day of reckoning for the white academy: Reframing success for African American women in STEM. *Cultural Studies of Science Education*, 1-10.

[15] Bers, M. U. (2008). *Blocks to robots: Learning with technology in the early childhood classroom.* Teachers College Press.

[16] Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2016). Developing fundamental programming concepts and computational thinking with ScratchJr in preschool education: a case study. *International Journal of Mobile Learning and Organisation, 10*(3), 187-202.

[17] Papert, S. A. (2020). *Mindstorms: Children, computers, and powerful ideas.* Basic books.

[18] Blanchard, S., Freiman, V., & Lirrete-Pitre, N. (2010). Strategies used by elementary schoolchildren solving robotics-based complex tasks: Innovative potential of technology. *Procedia-Social and Behavioral Sciences, 2*(2), 2851-2857.
[19] Sullivan, A., & Bers, M. U. (2016). Girls, boys, and bots: Gender differences in young children's performance on robotics and programming tasks. *Journal of Information Technology Education. Innovations in Practice*, 15, 145.
[20] Dawes, L., Long, S., Whiteford, C., & Richardson, K. (2015). Why are students choosing STEM and when do they make their choice?. In *Proceedings of the 26th Annual Conference of the Australasian Association for Engineering Education (AAEE2015)* (pp. 1-10). School of Engineering, Deakin University.
[21] Dugger, W. E. (2010, December). Evolution of STEM in the United States. In *6th biennial international conference on technology education research* (Vol. 10).
[22] Mataric, M. J., Koenig, N. P., & Feil-Seifer, D. (2007, March). Materials for Enabling Hands-On Robotics and STEM Education. In *AAAI spring symposium: Semantic scientific knowledge integration* (pp. 99-102).
[23] Papadakis, S., & Kalogiannakis, M. (2022). Exploring preservice teachers' attitudes about the usage of educational robotics in preschool education. In *Research Anthology on Computational Thinking, Programming, and Robotics in the Classroom* (pp. 807-823). IGI Global.
[24] Chalmers, C., Chandra, V., Hudson, S. M., & Hudson, P. B. (2012). Preservice teachers teaching technology with robotics. In *Australian Teacher Education Association (ATEA) 2012 Conference*.
[25] Hew, K. F., & Brush, T. (2007). Integrating technology into K-12 teaching and learning: Current knowledge gaps and recommendations for future research. *Educational technology research and development, 55*, 223-252.
[26] Ertmer, P. A. (2005). Teacher pedagogical beliefs: The final frontier in our quest for technology integration?. *Educational technology research and development, 53*(4), 25-39.
[27] Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: a systematic literature review. International Journal of STEM education, 6(1), 1-16.
[28] Kim, C., Kim, D., Yuan, J., Hill, R. B., Doshi, P., & Thai, C. N. (2015). Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching. *Computers & Education, 91*, 14-31.
[29] Chalmers, C. (2017). Preparing teachers to teach STEM through robotics. *International Journal of Innovation in Science and Mathematics Education, 25*(4).
[30] Belland, B. R., Kim, C., Zhang, A. Y., Baabdullah, A. A., & Lee, E. (2021). Using Process and Motivation Data to Predict the Quality With Which Preservice Teachers Debugged Higher and Lower Complexity Programs. *IEEE Transactions on Education, 64*(4), 374-382.
[31] Belland, B. R., Kim, C., Zhang, A. Y., Lee, E., & Dinç, E. (2022). Classifying the quality of robotics-enhanced lesson plans using motivation variables, word count, and sentiment analysis of reflections. *Contemporary Educational Psychology, 69*, 102058.

[32] Kim, C., Belland, B. R., Baabdullah, A., Lee, E., Dinç, E., & Zhang, A. Y. (2021). An ethnomethodological study of abductive reasoning while tinkering. *AERA Open, 7*, 23328584211008111.
[33] Kim, C., Dinç, E., Lee, E., Baabdullah, A., Zhang, A. Y., & Belland, B. R. (2023). Revisiting Analogical Reasoning in Computing Education: Use of Similarities Between Robot Programming Tasks in Debugging. *Journal of Educational Computing Research*, 07356331221142912.
[34] Wigginton, B., & Lafrance, M. N. (2019). Learning critical feminist research: A brief introduction to feminist epistemologies and methodologies. *Feminism & Psychology*, 0959353519866058.
[35] Murphy, P. K., Alexander, P. A., & Muis, K. R. (2012). Knowledge and knowing: The journey from philosophy and psychology to human learning. In K. R. Harris, S. Graham, T. Urdan, C. B. McCormick, G. M. Sinatra, & J. Sweller (Eds.), *APA educational psychology handbook, Vol. 1. Theories, constructs, and critical issues* (pp. 189–226). American Psychological Association. https://doi.org/10.1037/13273-008
[36] Wilkinson, S. (1988, January). The role of reflexivity in feminist psychology. In *Women's Studies International Forum* (Vol. 11, No. 5, pp. 493-502). Pergamon.
[37] Spradley, J. P. (2016). *The ethnographic interview.* Waveland Press.
[38] Denzin, N. K. (2001). The reflexive interview and a performative social science. *Qualitative research, 1*(1), 23-46.
[39] Kvale, S. (1994). *Interviews: An introduction to qualitative research interviewing.* Sage Publications, Inc.
[40] O'Brien, J. (Ed.). (2009). *Encyclopedia of gender and society* (Vol. 1). Sage.
[41] Kallio, H., Pietilä, A. M., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: developing a framework for a qualitative semi‐structured interview guide. *Journal of advanced nursing, 72*(12), 2954-2965.
[42] Benitti, F. B. V., & Spolaôr, N. (2017). How have robots supported STEM teaching?. *Robotics in STEM education: Redesigning the learning experience*, 103-129.
[43] Khanlari, A. (2013, December). Effects of educational robots on learning STEM and on students' attitude toward STEM. In *2013 IEEE 5th conference on engineering education (ICEED)* (pp. 62-66). IEEE.
[44] Weinberg, J. B., Pettibone, J. C., Thomas, S. L., Stephen, M. L., & Stein, C. (2007, June). The impact of robot projects on girls' attitudes toward science and engineering. In *Workshop on research in robots for education* (Vol. 3, pp. 1-5).
[45] Yang, K., Liu, X., & Chen, G. (2020). The influence of robots on students‟ computational thinking: A literature review. *International Journal of Information and Education Technology, 10*(8), 627-631.
[46] Barker, B. S., & Ansorge, J. (2007). Robotics as means to increase achievement scores in an informal learning environment. *Journal of research on technology in education, 39*(3), 229-243. *Computers & Education, 58*(3), 978-988.

[47] Nourbakhsh, I. R., Crowley, K., Bhave, A., Hamner, E., Hsiu, T., Perez-Bergquist, A., ... & Wilkinson, K. (2005). The robotic autonomy mobile robotics course: Robot design, curriculum design and educational assessment. *Autonomous Robots, 18*, 103-127.
[48] Shrewsbury, C. M. (1987). What is feminist pedagogy?. *Women's Studies Quarterly, 15*(3/4), 6-14.
[49] Alimisis, D. (2013). Educational robotics: Open questions and new challenges. *Themes in Science and Technology Education, 6*(1), 63-71.
[50] Eguchi, A. (2010, March). What is educational robotics? Theories behind it and practical implementation. In *Society for information technology & teacher education international conference* (pp. 4006-4014). Association for the Advancement of Computing in Education (AACE).
[51] Karypi, S. (2018). Educational robotics application in primary and secondary education. A challenge for the Greek teachers society. *Journal of Contemporary Education, Theory & Research, 2*(1), 9-14.
[52] Hiebert, J. (1999). Relationships between research and the NCTM standards. *Journal for research in mathematics education, 30*(1), 3-19.
[53] Webb, L. M., Allen, M. W., & Walker, K. L. (2002). Feminist pedagogy: Identifying basic principles. *Academic Exchange, 6*(1), 67-72.
[54] Denis, B., & Hubert, S. (2001). Collaborative learning in an educational robotics environment. *Computers in human behavior, 17*(5-6), 465-480.
[55] Yang, Y., Long, Y., Sun, D., Van Aalst, J., & Cheng, S. (2020). Fostering students' creativity via educational robotics: An investigation of teachers' pedagogical practices based on teacher interviews. *British journal of educational technology, 51*(5), 1826-1842.
[56] Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education, 72*, 145-157.