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Robotics in STEM Education: Enhancing Engagement, Skills, and Future Readiness

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Abstract: *The research explores the influence of robotics education on students' engagement, development of competencies, and career preparation in the field of STEM (Science, Technology, Engineering, Mathematics). With the increased integration of robotics into traditional curriculum, the development of fundamental 21st-century skills and better preparation for future careers are possible. However, evidence about its effectiveness in education has been scant. This, therefore, brings in the need for the current research, focusing on STEM students who are robotics enthusiasts, to explore how robotics activities influence engagement, competency development, and career readiness. Through a data-driven approach entailing surveys, interviews, and performance assessments, this study examines how robotics could effectively be integrated into STEM education to yield better student learning outcomes. The findings provide evidence-based recommendations on how best robotics integration can be optimized in educational settings by educators and curriculum developers. Besides technical competencies, it underlines the development of creativity, collaboration, and flexibility, or critical competencies at the core of a fast-changing technology environment.*

Keywords: Robotics Education, STEM Education, Student Engagement, Competency Development, Career Readiness, 21st-Century Skills, Problem-Solving, Instructional Design, Engineering Education, Technology Careers, Data-Driven Insights, Robotics Competitions, Skill Acquisition

I. INTRODUCTION

Recently, the focus on robotics in STEM education has increased due to greater potential for influencing student learning and engagement. Robotics provides an interactive learning environment that fosters such key 21st-century competencies as problem-solving, collaboration, and critical thinking (Bers, 2018). As technology continues to advance, the need for skilled workers in these areas is increasing, making robotics education important for preparing students for future careers in technology and engineering (Gura, 2018). Including robotics in education can improve learning and boost student interest in STEM subjects, which can directly impact career readiness and job opportunities in these fields. The study narrows down to the students of STEM disciplines involved in robotics projects and competitions, thereby giving meaningful insight into how robotics education affects student engagement, competence development, and career preparation. It does so to offer practical recommendations on the integration of robotics into the education process of STEM for improving the performances of the students.

A. Problem Statement

While current research is promising as an outcome of robotics education, there needs to be more solid empirical evidence about its impact, especially with respect to instructional design. Most of them rely either on anecdotal data or observational data; hence, this leaves a gap in knowledge with respect to what models are most effective for robotics-based curricula. This research, therefore, embarks on an empirical investigation into the impact of robotics education with particular emphasis on the need for data-driven insights to ascertain the impact of its contribution toward improving student interest, skill acquisition, and career preparedness in STEM. Consequently, this research addresses this issue and thus will contribute towards the development of instructional methods and the structuring of robotics curricula in light of best-preparing students to excel in a technological job marketplace increasingly swift in evolution and change.

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B. Purpose of study

This research is mainly focused on investigating the likely impacts of robotics education on the development of learner's skills and the preparation of the young for the world of work. The study will explore how robotics education enhances learning experiences, stirs up interest in the field of STEM, and prepares students for future opportunities in technology and engineering through insights from STEM students who are robotics enthusiasts. The research therefore, attempts to provide some empirically-based recommendations for educators and curriculum designers on how to include robotics in the process of STEM education so as to make students acquire other important competencies needed in the contemporary job market. Besides, it also develops instructional design frameworks that may foster core competencies beyond technical skills, including creativity, problem-solving, and collaboration skills for the 21st century.

C. Investigative Questions

This study is based on the following research questions that helped in better understanding the role of robotics in STEM education:

How does robotics education affect student interest in STEM?

The question explored the influence of robotics activities on students' interest in STEM studies, thus fostering long-term curiosity in the same study area.

What are the competencies developed in students during robotics activities?

This question investigated the different kinds of competencies developed in learners through robotics education, considering both technical, such as coding and engineering design, and soft skills, like teamwork, communication, creativity, and critical thinking. This is directed to enhance the broad range of educational outcomes of robotics education beyond mere technical expertise.

How do robotics prepare students for further challenges and careers?

The question aimed to ascertain the capacity in which robotics education prepares students to successfully engage in the ever-changing employment landscape and, mostly, in technology and engineering.

D. Hypothesis

- **Hypothesis 1 (H1):** The level of involvement in robotics education enhances student engagement in STEM studies and increases interest and further motivation to pursue this field academically.
- **Hypothesis 2 (H2):** It is expected that robotics training will help participants develop their technical and interpersonal competencies, consequently providing measurable improvements in such skills as coding, engineering design, team collaboration, effective communication, creative problem-solving, and critical analysis.
- **Hypothesis 3 (H3):** After education in robotics, students will be better prepared for their future challenges and careers in the fields of STEM and become more flexible while solving real-world problems.

II. LITERATURE REVIEW

Integrating robotics into STEM education has been a focus of much attention in recent years and educators and researchers seek to understand its impact on student learning and engagement. Robotics education provides a unique interactive environment that promotes active learning.

Studies have shown that robotics education can significantly improve student's engagement in STEM areas. According to Bers (2018), robotics allows for an interactive platform with problem-solving and collaboration. The interactive nature of robotics not only draws the students' attention but also develops long-term interest in the disciplines of STEM. Moreover, it has been revealed that students who participate in robotics competitions are more motivated with higher academic achievement than those who do not.

The literature has focused on the dual nature of robotics education in both technical and soft skills. While technical competencies in coding and engineering design are important for STEM careers, soft skills in teamwork, communication, and critical thinking are equally important in preparing students for the workforce (Bers, 2018). The

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development of these competencies through robotics education is supported by empirical evidence, suggesting students who participate in robotics activities demonstrate enhanced problem-solving skills and creativity (Gura, 2018).

As the labor market increasingly demands people with a diverse skill set, robotics education plays a crucial role in preparing students for the challenges in STEM careers. Research indicates that robotics education equips students with the required skills to adapt to the rapidly changing technological landscape (Gura, 2018). By fostering creativity, flexibility, and teamwork, robotics education prepares students to effectively navigate complex real-world scenarios.

Taken altogether, the literature is therefore very supportive of such claims that robotics education indeed builds up student engagement; other skills are also grown while preparing students for bright, rewarding futures within this complex field of STEM careers. Nevertheless, additional empirical research is needed to fully establish a comprehensive understanding of the most effective instructional designs for integrating robotics into STEM curricula in order to maximize its impact on student learning outcomes and career readiness in an increasingly competitive job market.

III. RESEARCH DESIGN AND METHODOLOGY

This research study uses a mixed-methods design to explore the effect of robotics education on student engagement, competency development, and career preparation in STEM fields. It comprises three main elements: quantitative surveys, qualitative interviews, and performance assessments.

Performance assessments were conducted to ascertain the practical competencies developed through robotics education. Participants were engaged in a specific robotics-related challenge that required the application of both technical and soft skills in order to complete it. These included a rubric-based assessment on problem-solving skills, teamwork, creativity, and technical skills. Evaluators (instructors or robotics educators) assessed performance using a detailed rubric measuring teamwork, problem-solving, technical skills, creativity, and engagement.

For quantitative surveys, a structured survey was designed and distributed to students who participated in the challenge. This questionnaire contained questions using the Likert scale, which aimed to measure the level of engagement, interest in STEM subjects, and perceived competency development-both technical and soft skills of the students. Performance assessment scores are correlated with the survey responses to determine the relationship between practical skills and self-reported competencies.

In-depth discussions with 10 students volunteering from the survey group also were carried out for qualitative interviews. These interviews were utilized to delve into their personal experience of robotics education and how this has so far influenced their engagement with school, their skill acquisition, and their career visions. An interview guide is used in guiding the conversation; thus, responses would be open and flexible. Major topics involved student motivations for participating in robotics, what skills they believe they have developed, and how they believe robotics education prepares them for future careers. The interviews are audio-recorded, transcribed verbatim, and then analyzed using thematic analysis, where common themes and insights related to the impact of robotics education will be identified.

The participants targeted for this research are STEM students engaged in robotics education or enrolled in programs incorporating robotics into their curricula. The selection was due because these participants' personal experiences would provide rich information on the impact of learning robotics. The sample size of approximately 30 students was drawn from different institutions globally offering robotics programs. This included high schools with robotics clubs or courses, Universities offering robotics engineering or related programs, and Community colleges with STEM-focused programs. The participants were selected in two ways. First, this was the contact with the schools to further the research and encourage student participation in the study. The second approach was working through social networking sites, forums, and online discussions in order to target people interested in robotics. Great attention was paid to proper sampling, choosing representatives of diverse groups according to age, gender, or educational background.

Data from the surveys were analyzed using descriptive statistics and inferential analyses, such as t-tests and ANOVA, among others, to test for significant relationships between robotics education and the variables of interest.

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A. Survey Questions

Questions to measure the level of engagement, interest in STEM subjects, perceived competency, and career preparation are as follows:

1. On a scale of 1 to 5, how engaged do you feel during robotics activities? (1 = Not engaged, 5 = Very engaged)
2. How often do you participate in robotics competitions? (Never, Rarely, Sometimes, Often, Always)
3. Rate your confidence in the following skills after participating in robotics education (1 = Not confident, 5 = Very confident)

- Coding
- Engineering design
- Teamwork
- Communication

4. How well do you believe robotics education has prepared you for a career in STEM? (1 = Not prepared, 5 = Very prepared)
5. What specific skills do you think are most important for your future career?
6. Would you be interested in participating in future robotics competitions or activities? (Yes/No)
7. Please provide any additional comments or feedback on your experience with the robotics activities.

B. Interview Questions

Below are the interview questions to be asked during zoom interviews:

1. What strategies did you use to solve challenges during the robotics task?
2. Were there any unexpected obstacles during the activity, and how did you overcome them?
3. How confident were you in applying technical skills like coding or design during the task?
4. Can you describe an aspect of your design that you feel was particularly creative or innovative?
5. How did you communicate your ideas or feedback with your teammates or the evaluator during the activity?
6. What did you enjoy the most about the challenge, and what could be improved to enhance the experience?

C. Data Collection and Analysis

The 30 participants took the performance assessments on the online practical robotics challenge in a group and scored on a rubric individually. A structured survey was administered to them right after the challenge, having their responses collected online via a secure online survey platform. In-depth interviews were conducted via an online platform with a subsample of 10 participants and collected detailed information about their experiences.

Quantitative data analysis was done using SPSS software, among other statistical software. *Descriptive statistics were used to summarize the data, while tests like t-tests and ANOVA showed* important *relationships* among different factors. Qualitative data were coded from interview transcripts to identify common themes related to engagement, skill development, and career preparation. Scores from performance assessments were also analyzed for their relationships to the survey responses as evidence of skill development.

IV. RESULTS AND FINDINGS

The data for this study was gathered from 30 STEM students who are actively participating in robotics education at various schools. The sample was chosen to ensure a mix of experiences and backgrounds: 15 high school students and 15 undergraduate students. 30 students engaged in robotics education programs: 15 high school students, 10 university students, and 5 community college students globally. Amongst the 20 students, 14 were male, and 16 were female in the age range from 15 to 25 years. The survey results are indicated in Figures 1-4 and Tables 1-4.

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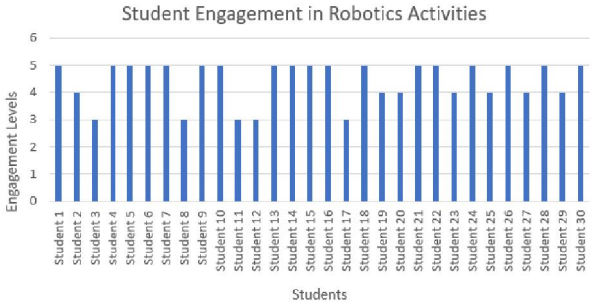

Figure 1: Student Engagement in Robotics Activities

Table 1: Frequency of Participation in Robotics Competitions

Frequency	Number of Students	Percentage (%)
Never	1	3%
Rarely	5	17%
Sometimes	9	30%
Often	10	33%
Always	5	17%

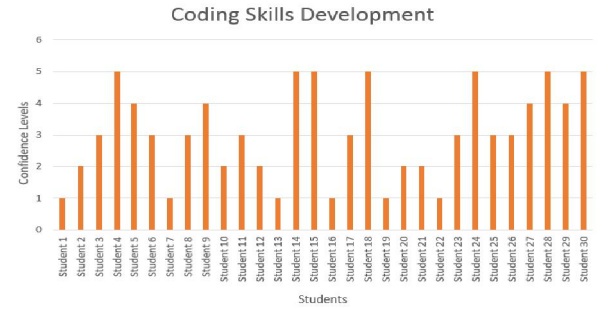

Figure 2: Coding Skills Development

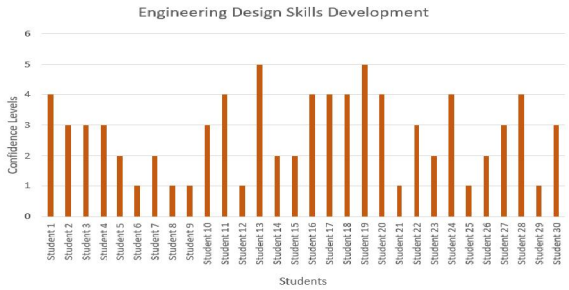

Figure 3: Engineering Design Skills Development

Table 2: Confidence in Competency Development After Robotics Education

Competency	1(Not Confident)	2	3	4	5(Very Confident)
Coding	1	4	10	8	7
Engineering Design	2	3	7	10	8
Teamwork	0	2	9	11	8
Communication	0	3	8	12	7

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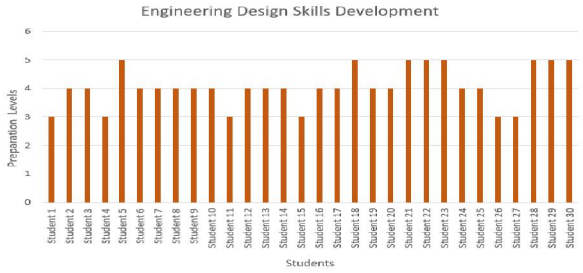

Figure 4: Career Preparation through Robotics Education

Table 3: Skills Perceived as Most Important for Future Careers

Skill	Number of Students	Percentage (%)
Coding	20	67%
Collaboration	18	60%
Critical Thinking	15	50%
Creativity	12	40%

Table 4: Overall Survey Result

Survey Categories	Average Scores out of 5
Engagement	4.23
Coding Skills Development	3.75
Engineering Design Skills Development	4
Career Preparation	3.77

Common themes from responses to the open-ended question "What specific skills do you think are most important for your future career?" were that 20 students mentioned the importance of coding skills for software development, engineering, and robotics careers, 18 emphasized the importance of collaboration and effective communication for team-based projects, 15 identified critical thinking and problem-solving as some of the most important skills to solve real-life problems, and 12 highlighted the role of creativity in working towards solutions.

A. Interview Findings:

The interview gave a clear picture of the students' experiences in the program. The common gains were increased confidence, better problem-solving skills, teamwork, collaboration, and an interest in pursuing a career in STEM fields. As can be seen from, increased confidence and problem-solving skills were the most commonly cited outcomes, with students reporting that the program helped them to feel more confident in their ability to tackle complex problems and work as part of a team. As shown in Table 5, many students also reported a higher level of interest in pursuing STEM-related careers, which indicated that the program had a positive influence on the student's career aspirations.

Table 5: Qualitative Interview Findings

Interview Themes	Frequency in Mentions
Increased Confidence	12
Problem-solving skills	15
Teamwork and Collaboration	10
Interest in STEM careers	14

Figure 5 demonstrates that students scored highest in problem-solving, technical skills and teamwork are the next highest scores, showing that students have strong technical abilities which can be put into place both in practical settings and within a group environment. Although creativity remains strong, lower scores in this area indicated there is some room for further improvement.

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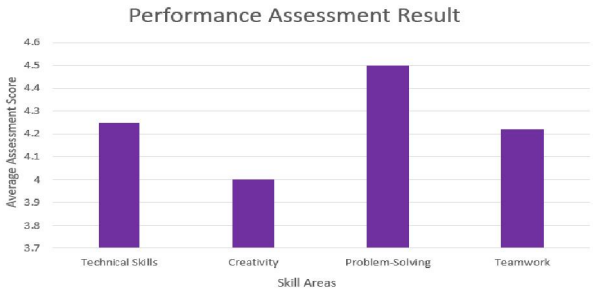

Figure 5: Performance Assessment Result

These findings show that the program has helped students improve both technical and personal skills. It also pointed out areas that need improvement, like teamwork and communication in group tasks.

B. Data Analysis and Findings

A majority of the students (56%) reported a high engagement during robotics activities with scores of 4 or 5, showing that robotics is effective in raising student's interest in science, technology, engineering, and mathematics subjects. This seems to nurture curiosity and involvement in activities that raise awareness about the subject matter. However, whereas 83% of students report using robotics competitions at least sometimes, only 17% engage on a regular basis. In this case, despite some enthusiasm for participating in robotics-related activities, there exists great potential to increase student interest in the frequency with which students participate in competitive aspects of robotics. Accordingly, educators could encourage increasing student's involvement in these valuable extra-curricular opportunities by allowing increased competitiveness within the curriculum or creating school-wide events.

In terms of skill development, robotics education appears to be particularly effective in nurturing soft skills like teamwork, communication, and problem-solving. Most students (64%) said they feel confident in their ability to work well with others and communicate effectively-important skills for school and work. However, when it comes to technical skills-like engineering design and coding-things get different. Although half the students were confident in the engineering design process, only 50% had the same feelings about their abilities in coding. It showed that even though the progresses in these areas exist, coding is still challenging, especially for students who previously had less exposure. There is a gap to fill as this means that programming classes definitely need more support if all learners are to develop the necessary technical proficiency.

About career preparation, 63% felt well-prepared for a career in STEM; of those, 30% felt very well-prepared. This finding reinforces the value of robotics education not only in providing technical skills but also in essential soft skills valued highly in STEM careers. Students also emphasized the role of robotics in fostering innovation and adaptability-skills integral to success in an ever-changing technological world. This combination of technical proficiency with critical soft skills arms them to handle future challenges at work with confidence and imagination.

V. INSTRUCTIONAL DESIGN IMPLICATIONS

These results also confirm that the integration of robotics education in the framework of the STEM curriculum may serve to better student engagement, competency development, and career readiness. Educating students in robotics will help develop a greater interest in students studying at STEM schools, develop their technical and soft skills, and build a better future in technology that is rapidly changing. These are just a few benefits, but to realize all these advantages, educators and designers of the curriculum must focus on integrating robotics in a systematic manner into already existing curricula on STEM and align it with practical uses of science, technology, engineering, and mathematics. During project-based learning, students can use robotics to solve real-world challenges that help develop problem-solving and critical thinking skills. Further, such integration of robotics must support different learning modes, such as hands-on activities, collaborative projects, and online platforms.

Besides, while technical skills are necessary, the development of soft skills like teamwork, communication, and problem-solving should be stressed in the robotics curriculum. The findings of this study indicate that robotics education provides an effective platform for developing these competencies, which are highly relevant both at school

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and in professional life. Educators should create opportunities for students to engage in collaborative activities and reflective practices that enhance these skills. This approach will also help provide students with both technical skills and prepare them for the challenges of teamwork and communication that they will go through during their careers in STEM. Moreover, periodic assessment and feedback are very important to keep track of the students' strengths and weaknesses. Informing students on time with feedback that is helpful elicits an improvement in their skills and knowledge so that they may further grow and learn.

VI. LIMITATIONS

One of the major limitations of this study includes the small sample size used, which comprised 30 students. It may limit the generalization of findings in other contexts. A more diverse sample might provide more comprehensive insight into the effect of robotics education across a range of different educational settings. Also, the research is based on self-reported data that may be biased by the overestimation of students in reporting their engagement and skill levels. In future studies, the combination of self-reported data with observations or performance assessments would increase the reliability of the results. This study also focuses mostly on the immediate impacts of robotics education, while the long-term effects have been less explored. The long-term impact of robotics education on the career trajectory and the skill retention of students calls for longitudinal studies. While this research focused on a predefined set of competencies, teamwork, and problem-solving, for example-future research could be expanded to explore creativity, adaptability, and technological literacy, among others.

VII. FUTURE DIRECTIONS

Future research that follows students over a period of time can take these findings a step further by showing the long-term effects of robotics education. Other studies might compare teaching methods for robotics to inform a broad knowledge base on how best to impact the skills and learning of students. Increasing research in more diverse demographics, especially in underrepresented groups in STEM fields, could help to identify barriers and opportunities to enhance inclusivity in robotics education. It could also provide opportunities to enhance learning experiences and outcomes by investigating the integration of emerging technologies, such as artificial intelligence and virtual reality, into robotics education.

VIII. DISCUSSION AND COMPARISON WITH LITERATURE

The results of this study confirm the existing literature on how robotics education contributes to the improvement of student's engagement, development of competencies, and career readiness in general in STEM subjects. Robotics has been recognized as an effective way to improve learning processes and develop key 21st-century competencies by students within educational curricula (Bers, 2018; Gura, 2018).

The results indicated that a majority of the students reported a high level of engagement during the robotics activities, 56% scored 4 or 5 on the engagement scale. This agrees with earlier studies showing that robotics education clearly helps increase student interest in STEM subjects (Bers, 2018). The hands-on nature of robotics, which involves problem-solving and teamwork, grabs students' attention and keeps them interested in STEM for the long term. According to Bers, 2018, the majority of students who were involved in the study showed that 83% participated in robotics competitions at least sometimes, while 17% did so regularly. Thus, this shows that more can be done to involve students in competitive robotics activities, which have been found to be associated with increased motivation and better academic results.

The findings of this study on competency development clearly indicate that robotics education enhances technical and soft skills. A large portion of the students claimed confidence in their competencies in teamwork, communication, and problem-solving, as shown in the literature to be two sides of the coin for the competencies developed by robotics education (Bers, 2018). While technical competencies in coding and engineering design were also reported, the study noted a variation in confidence levels, with only 50% feeling confident in coding. This shows the challenges that students face in developing technical skills, as emphasized by Gura (2018), who noted that technical proficiency remains a very important area of focus in robotics education.

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In this regard, 63% of the students were well-prepared for careers in STEM. This corroborates the literature that says robotics education provides the essential grounding for students to meet the challenges in a rapidly changing technological world (Gura, 2018). The emphasis on creativity, flexibility, and teamwork as integral skills for future job performance is in line with the findings of Bers (2018), who noted that robotics education not only provides technical knowledge but also develops critical soft skills necessary in the workforce.

A. Contributions to Existing Knowledge

The study contributes to the literature by providing empirical evidence regarding the effectiveness of robotics education in enhancing students' engagement and competency development. Most of the studies conducted in the past have depended much on stories or observations, while this study uses a mixed-methods approach, combining surveys, interviews, and performance assessments to get a full understanding. This approach of basing on real data is important in improving the methods of teaching and shaping robotics courses (Gura, 2018).

IX. CONCLUSION

These findings constitute strong evidence that robotics education positively influences the development of student skills, career readiness, and engagement in STEM subjects. This aligns with the literature and thus calls for integrating robotics into academic and practical learning by educators and course designers to provide students with the competencies they need to navigate an increasingly complex, technology-driven world. The importance of robotics education in developing technical and soft skills is well documented in the literature regarding employability. This education enhances not only technical competencies but also problem-solving, teamwork, and communication-skills-everything required for success in the STEM workplace.

The limitations of this study need to be addressed, and evidence-based instructional strategies must be incorporated to create a more dynamic and inclusive learning environment that meets diverse student needs. As robotics becomes increasingly integrated into the STEM curricula, students will gain not only technical expertise but also the ability to navigate the challenges and opportunities of a rapidly evolving technological landscape. Efforts should be directed at increasing student participation in robotics competitions to provide hands-on experience and exposure to real-world applications. While the development of soft skills is a relative strength, more emphasis needs to be placed on enhancing coding and engineering design skills, especially for students with limited backgrounds in these areas. Improvement in these technical competencies would contribute to a more holistic and balanced educational experience for better preparation of students in STEM careers.

This research again consolidates the importance of robotics education in developing engagement skills and preparing students for success in the dynamic world of STEM. It informs approaches toward curriculum refinement so that students are better prepared with the appropriate workplace skills needed for a technology-driven workforce.

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