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Automatic Feedback in Mathematics Education: A Pathway to Robotics and Computational Thinking

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ABSTRACT

Background: GeoGebra's automatic feedback tasks emerge as an innovation in mathematics education, contributing to development of robotics-related skills. **Objectives:** To investigate how the creation and use of these tasks enhance self-regulated learning, conceptual comprehension and computational thinking in Portuguese-speaking contexts. **Design:** Literature review integrated with a comparative empirical study, analysing experiences of teachers in different countries. **Environment and participants:** Four teachers from Brazil, Portugal and Cape Verde, involved in a continuous training program focused on GeoGebra-assisted learning, complemented by international research sources. **Data collection and analysis:** The study collected reports of teaching practices and performance data from the participants, analysed based on parameters of development of skills in robotics and the comparison of different realities. **Results:** There was increased participant engagement, improvement in problem solving, spatial visualization and algorithmic thinking, but also challenges in technical training and instructional resource development. **Conclusions:** The adoption of tasks with automatic feedback in GeoGebra demonstrates potential to bring mathematics education closer to robotics and promote interdisciplinary practices. Investments in continuous teacher training and innovative pedagogical strategies are recommended to optimize the integration of GeoGebra in the Mathematics curriculum and strengthen STEAM education.

Keywords: Mathematics Education; Automatic Feedback; Robotics; Computational Thinking.

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Feedback Automático na Educação Matemática: um Caminho para a Robótica e o Pensamento Computacional

RESUMO

Contexto: As tarefas de feedback automático do GeoGebra emergem como inovação na educação matemática, contribuindo para o desenvolvimento de competências relacionadas com a robótica. **Objetivos:** Investigar como a criação e utilização dessas tarefas potenciam a aprendizagem autorregulada, a compreensão conceptual e o pensamento computacional em contextos lusófonos. **Design:** Revisão de literatura integrada a um estudo empírico comparativo, analisando experiências de professores em diferentes países. **Ambiente e participantes:** Quatro professores do Brasil, de Portugal e de Cabo Verde, envolvidos num programa de formação contínua centrado na aprendizagem assistida pelo GeoGebra, complementados por fontes de pesquisas internacionais. **Coleta e análise de dados:** O estudo recolheu relatos de práticas docentes e dados de desempenho dos participantes, analisados com base em parâmetros de desenvolvimento de competências em robótica e na comparação das diferentes realidades. **Resultados:** Houve aumento do envolvimento dos participantes, melhoria na resolução de problemas, visualização espacial e pensamento algorítmico, mas também desafios no treinamento técnico e no desenvolvimento de recursos instrucionais. **Conclusões:** A adoção de tarefas com feedback automático no GeoGebra demonstra potencial para aproximar a educação matemática da robótica e promover práticas interdisciplinares. Recomendam-se investimentos em formação docente contínua e estratégias pedagógicas inovadoras para otimizar a integração do GeoGebra no currículo de Matemática e reforçar a educação STEAM.

Palavras-Chave: Educação Matemática; Feedback Automático; Robótica; Pensamento Computacional.

INTRODUCTION

The growing integration of digital technology into education is reshaping the way Mathematics is taught and learned. GeoGebra—a dynamic mathematics software widely used in the classroom—has made it possible to create interactive tasks that provide students with immediate, automated feedback. It is believed that this automatic feedback in Mathematics exercises supports student learning by offering instant error correction and guidance, helping students to self-regulate and remain motivated (Abar et al., 2022; Abar et al., 2024). This innovation arises at a time when education systems worldwide seek to equip students with 21st-century skills, including those required for robotics and computational thinking.

Teaching robotics-related skills in schools introduces interdisciplinary challenges: teachers must continually adapt and expand their knowledge in areas such as technology, engineering, and mathematics (Md-Ali & Khor, 2018). Strengthening basic mathematics skills—such as problem-solving, logical reasoning, and spatial visualisation—is viewed as a fundamental step towards successful learning in robotics and other STEM fields. GeoGebra's interactive tasks, which frequently involve the visualisation and manipulation of mathematical objects, present a promising avenue for developing these foundations (Suparman et al., 2024).

Educators in various countries have explored the potential of GeoGebra not only to improve learning outcomes in Mathematics but also to foster transferable skills relevant to robotics. In Portuguese-speaking contexts such as Brazil, Portugal, and Cape Verde, collaborative research projects have been launched to train teachers in designing and implementing GeoGebra tasks with automatic feedback (Abar & Silva, 2024; Pinkernell et al., 2023). These projects aim to modernise Mathematics instruction, making it more interactive and student-centred, while responding to regional needs for enhanced STEM education and professional teacher development. Crucially, they examine how teachers incorporate technology into their practice and how students respond to these new learning activities. Given the global interest in STEM integration, comparing the experiences from Brazil, Portugal, and Cape Verde with perspectives from other countries—where similar approaches, including automated assessment systems and dynamic mathematics software, have been studied—proves beneficial (Veber et al., 2022).

The increasing adoption of digital technology in Mathematics Education has opened new possibilities for developing computational thinking and problem-solving skills. GeoGebra's interactive visualisation and automatic feedback functionalities have emerged as powerful tools to facilitate mathematics learning. Over recent years, researchers have investigated its potential beyond conventional classroom teaching, particularly in cultivating skills relevant to robotics (Engelbrecht & Borba, 2024). Robotics education requires students to engage in algorithmic thinking, logical reasoning, and iterative problem-solving—skills closely aligned with the capabilities of GeoGebra's dynamic geometry and algebra environments. Nevertheless, there remains limited research on how active teacher participation in creating GeoGebra tasks with automatic feedback can augment students' robotics skills.

This study pursues two objectives. First, it provides a comprehensive literature review concerning automatic feedback tasks in GeoGebra for Mathematics Education and their contribution to developing skills associated with robotics. Second, it seeks to fill existing gaps by investigating the experiences of four Mathematics teachers from Brazil, Portugal, and Cape Verde, who designed and implemented GeoGebra-based tasks with automatic feedback in their classrooms.

The following literature review prioritises empirical studies focusing on teacher experiences in Brazil, Portugal, and Cape Verde, and contrasts these findings with international investigations. The review is organised as follows. First, in the Literature Review section, we examine previous studies on automatic feedback in Mathematics Education and the use of GeoGebra to enhance learning, highlighting reported impacts on skills pertinent to robotics. Next, the Methodology section describes the procedure for identifying and selecting relevant studies. The Results section synthesises key conclusions and emerging themes from the literature, particularly the experiences reported by teachers, their students' learning gains in the target countries, and comparable results in other contexts. The Discussion section interprets these findings, examining the implications for Mathematics teaching practices and the promotion of robotics and STEM skills, also considering contextual similarities and differences. Finally, in Concluding Remarks, we summarise the main ideas, presenting recommendations for educators and policymakers, as well as suggestions for future research in this interdisciplinary field.

Moreover, this study explores how GeoGebra tasks with automatic feedback influence students' conceptual understanding, their problem-solving abilities, and their engagement with robotics-oriented reasoning. Thus, it contributes to the debate on technology-enhanced Mathematics Education. By comparing the findings with studies from other countries, this work also offers a broader perspective on GeoGebra's impact on interdisciplinary competence development in STEM.

LITERATURE REVIEW

GeoGebra and Interactive Learning

GeoGebra has been extensively investigated for its importance in Mathematics Education, especially because it promotes active learning through dynamic visualisations and automated feedback (Richard et al., 2023). Several studies indicate that interactive mathematics tasks using GeoGebra encourage students to engage in exploratory learning, leading to deeper understanding of geometric and algebraic concepts (Ortiz-Laso et al., 2023). Automated feedback mechanisms have proven effective in supporting self-regulated learning by providing immediate responses to students' inputs, enabling them to detect and correct errors in real time (Lagrange et al., 2024).

Numerous investigations have also examined the intersection of GeoGebra with computational thinking and robotics education. Chytas et al. (2024) note that students participating in GeoGebra-based activities demonstrated more developed problem-solving strategies and algorithmic reasoning. Similarly, Abar et al. (2024) suggest that using automated feedback in GeoGebra enhances students' logical sequencing skills, a crucial element in robotics programming. Furthermore, comparative studies across countries highlight differences in how GeoGebra is implemented in teaching. For example, Kim and Lee (2021) found that in South Korea, GeoGebra is mainly utilised for automated assessment, whereas in Europe it is more frequently used within inquiry-based learning methodologies.

Automatic Feedback in Mathematics Education

Research in educational assessment underscores the value of immediate, informative feedback for student learning. Automatic feedback tasks are digital, interactive exercises that instantly inform students whether their answers are correct and often provide hints or corrective guidance in the event of errors. In Mathematics, such tasks have been associated with enhanced student engagement and improved self-correction habits (Abar et al., 2022). Nicol and Macfarlane-Dick's (2006) formative assessment model posits that effective feedback guides students to identify gaps in their understanding and fosters self-regulation. Automatic feedback aligns with these principles by delivering prompt, specific reactions without requiring direct teacher intervention.

There is empirical evidence that automatic feedback can boost learning outcomes. In a Brazilian study, Abar et al. (2024) observed that integrating immediate feedback into Mathematics tasks kept students motivated and allowed them to progress at their own pace, as the system provided incentives for correct answers and hints for incorrect attempts. Students were able to solve the majority of proposed problems successfully, crediting these instant prompts for helping them overcome difficulties. In addition, automatic feedback underpins a formative approach to assessment by viewing errors as opportunities for learning. By analysing the most frequent errors recorded by the system, teachers can identify patterns of misunderstanding and address them in subsequent lessons (Abar et al., 2024). Overall, the literature shows that well-designed automatic feedback fosters active learning, reduces students' uncertainty about their performance, and helps bridge the gap between their current and desired levels of understanding.

Computational Thinking, Robotics Skills, and Education

The rising emphasis on STEAM (Science, Technology, Engineering, Arts, and Mathematics) education has brought computational thinking (CT) and robotics to the forefront of Mathematics and Technology Education (Santos et al., 2024). Computational thinking comprises a set of cognitive processes enabling students to break complex problems into structured steps, design algorithms, and apply logical reasoning—essential skills in robotics (Hamed, Wong & Khambari, 2025). This section explores the interconnections among computational thinking, robotics skills, teacher training, and mathematics learning at primary and secondary levels.

Computational Thinking and Robotics

Computational thinking provides the cognitive bedrock for robotics. Wing (2006) defined computational thinking as encompassing decomposition, pattern recognition, abstraction, and algorithm design—all vital in programming robots (De la Hoz Serrano & Melo Niño, 2024). Studies show that students who engage in robotics-based learning environments demonstrate higher levels of computational thinking through building algorithms, debugging programs, and iterating solutions (López-Bouzas & Castañeda Fernández, 2024).

GeoGebra’s automatic feedback capabilities align closely with this process by offering iterative feedback, allowing students to test, refine, and optimise their solutions—a core practice in computational thinking (Sadik & Budiyanto, 2024). By manipulating variables in dynamic mathematical models, students acquire computational reasoning skills that can be transferred to programming and robotic automation.

The Role of Teacher Training in Developing Computational Thinking and Robotics Skills

Teachers play a key role in integrating computational thinking and robotics into Mathematics Education. However, research shows that many Mathematics teachers lack formal training in computational thinking and have difficulty connecting mathematics concepts to applications in robotics (G’ofurov & Sa’dullayeva, 2025). Professional development programmes should include training that equips teachers with algorithmic problem-solving approaches, hands-on experience with robotics tools and dynamic mathematics software, and strategies for incorporating CT-based lesson plans in their Mathematics classes.

Recent interventions have demonstrated that teachers trained in computational thinking pedagogy are more capable of designing interactive lessons linking mathematical principles to robotics applications (Shi et al., 2025). In addition, professional development initiatives that combine GeoGebra task design with a focus on robotics enable teachers to gain confidence in integrating technology, leading to higher student engagement and better learning outcomes (Gaur & Kalita, 2024).

Computational Thinking and Robotics in Secondary Education

Secondary education is a crucial phase for developing robotics skills, as students move from basic mathematical operations to solving advanced problems using digital tools. Research has shown that incorporating robotics into secondary Mathematics curricula enhances spatial reasoning and algorithmic logic (Suparman et al., 2024), increases student engagement and motivation in STEM fields (Ugolini & Kakavas, 2024), and bolsters persistence in tasks such as debugging robot code (Inventado et al., 2017).

GeoGebra’s dynamic geometry and algebraic environments support secondary students by helping them connect abstract mathematical representations to real-world robotics applications (Hamed et al., 2025). The addition of automatic feedback further fosters self-regulated learning, which is fundamental for students transitioning to higher education in STEM fields (Veber et al., 2022).

Computational Thinking and Robotics in Primary Education

While most studies focus on secondary education, recent research suggests that early exposure to computational thinking and robotics yields long-term STEM proficiency benefits (Varghese et al., 2025).

At Primary-level initiatives featuring block-based programming platforms, educational robots, and interactive Mathematics software have shown notable improvements in problem-solving. Also, in this level GeoGebra serves as a gateway to computational reasoning, enabling younger students to experience sequences, loops, and conditional statements in a mathematical context (Fang et al., 2025). Although pupils at this level do not typically undertake full robot programming, their initial experiences with dynamic feedback exercises in Mathematics lay a foundation for future robotics learning.

Robotics Skills and Aptitudes for Teachers

Integrating automatic feedback tasks in GeoGebra within Mathematics Education not only benefits student learning but also advances teachers' professional development. To implement these tasks effectively, Mathematics teachers require skills aligned with robotics education and, more broadly, with STEM instruction. Table 1 outlines key robotics-related competencies and aptitudes for teachers that can be developed through GeoGebra-based learning.

Table 1

Robotics Competencies and Aptitudes for Teachers

Competencies and Aptitudes in Robotics	Description
Algorithmic Thinking and Computational Logic	Teachers designing tasks in GeoGebra must structure conditional feedback, relying on logical operations and sequential rules, mirroring the algorithmic thinking used in robot programming (Chytas et al., 2024).
Reasoning and Spatial Visualisation	A crucial competence in robotics involves understanding spatial relationships, essential for planning and controlling robotic movements (Suparman et al., 2024). Teachers who create geometry activities in GeoGebra involving transformations (e.g. rotations and translations) enhance their ability to visualise spatial configurations, transferable to robotics instruction.
Pedagogical Adaptability in Digital Environments	Incorporating feedback mechanisms in GeoGebra requires teachers to adjust their instructional methods to technology-supported learning environments (Md-Ali & Khor, 2018). They must learn to interpret student responses in automated systems and adapt teaching strategies, just as in robotics, where real-time problem-solving is essential.
Debugging and Error Diagnosis	In both robotics and GeoGebra task design, educators must anticipate and address students' conceptual errors, creating feedback that guides them to seek solutions. By creating automated mathematics assessments, teachers develop an iterative mindset, akin to code debugging in robotics.

Collaboration and Interdisciplinary Thinking	Robotics education demands multidisciplinary knowledge spanning Mathematics, Engineering, and Computer Science. Teachers involved in GeoGebra task design report heightened awareness of the connection between mathematical concepts and real-world applications (Abar & Silva, 2024). The collaborative nature of professional development initiatives with GeoGebra fosters an interdisciplinary mindset, vital in modern STEM teaching.

Robotics Competencies and Student Learning

GeoGebra tasks with automated feedback help students build problem-solving capacity, reinforcing the cognitive and technical skills required in robotics and Engineering. Table 2 summarises the main robotics-related skills enhanced by GeoGebra-based learning.

Table 2

Robotics Competencies and Student Learning

Competencies and Aptitudes in Robotics	**Description**
Problem-Solving and Logical Sequencing	Students interacting with GeoGebra's automated feedback engage in logical reasoning to fix mistakes, mirroring the debugging process in robotics programming. The feedback cycle encourages the sequential decomposition of problems, crucial for designing robotics algorithms (Downs et al., 2024).
Spatial Visualisation and Kinematic Awareness	Robot programming often requires students to mentally simulate movements and anticipate transformations. GeoGebra's dynamic geometry tools strengthen the ability to visualise rotations, reflections, and translations, enhancing the spatial cognition needed to understand robotic motion control (Suparman et al., 2024).
Self-Regulated Learning and Iterative Improvement	GeoGebra's feedback system allows students to experiment with different approaches, progressively refining their understanding via trial and error. This reflects the engineering process in robotics, where testing, refining, and

	debugging designs is necessary (Abar et al., 2024).
Computational Thinking and Algorithm Design	GeoGebra tasks often require students to follow logical input-output sequences, like the logic used in robotic programming and automation (Chytas et al., 2024).
Engagement, Motivation, and Gamification Benefits	Empirical studies show higher engagement levels when students use dynamic tasks with feedback (Md-Ali & Khor, 2018). Game-like features in many of these exercises encourage persistence—essential in robotics, where debugging and problem-solving demand sustained effort.

Teachers' Experiences in Brazil, Portugal, and Cape Verde

In Brazil, Portugal, and Cape Verde, some teachers have led the way in experimenting with GeoGebra's automated feedback features, as part of efforts to modernise Mathematics teaching. A standout example is a multi-phase research project first launched in Brazil and subsequently expanded via partnerships with Portuguese and Cape Verdean educators (Abar & Silva, 2024).

Initial Phase (Brazil): Nine volunteer Mathematics teachers (from secondary and higher education) took part in a training programme to create GeoGebra-based assessment tasks with automatic grading (Abar & Silva, 2024). Many of these teachers had already been using GeoGebra for demonstrations but learnt how to design interactive tasks, set up conditional feedback, and analyse students' solution paths. The theoretical framework guiding the project was TPACK (Technological Pedagogical Content Knowledge), recognising the skilled interweaving of content, pedagogy, and technology required to implement such innovations. However, some participants struggled to develop automated feedback resources due to limited technical expertise and the complexity of predicting different solution strategies (Abar & Silva, 2024). Even so, by the end of this pilot phase, some teachers successfully created effective GeoGebra tasks—such as gamified fraction-addition exercises with built-in feedback—and demonstrated a solid understanding of the pedagogical value of this approach.

Second Phase ("Group 2"): Building on the lessons from Brazil ("Group 1"), the project coordinators began a second phase ("Group 2") involving teachers from Portugal and Cape Verde, alongside colleagues from

Brazil (Abar & Silva, 2024). In this expanded phase, 14 teachers participated—six from Portugal, three from Brazil, one from Cape Verde (who involved three of his own students in classroom trials), and one from Mozambique—collaborating via regular online meetings. The partnership with the Instituto GeoGebra de Portugal provided additional technical support and mentoring. Through monthly workshops, these educators co-designed and refined GeoGebra activities with automatic feedback for their students. Even those with only minimal training were able to customise (re-parameterise) the applications to align with their curricula, giving them the confidence to integrate these resources into their teaching practices.

The experiences in Portugal and Cape Verde within this project reinforce the idea that teacher collaboration and iterative design are critical to the successful adoption of new technologies (Abar & Silva 2024). The exchange of ideas and interim results enabled participants to gain a broader understanding of common student difficulties and ways to address them through feedback. Overall, early results from "Group 2" show that more teachers succeeded in developing functional classroom materials compared to the first phase in Brazil, suggesting that international collaboration and a longer training period contributed to improved outcomes.

Similar Findings from Other Countries

Initiatives in Brazil, Portugal, and Cape Verde parallel comparable global efforts to leverage technology to enhance Mathematics Education. In Slovenia, for example, Tomić, Aberšek, and Pesek (2019) focused on employing GeoGebra to train spatial-visualisation skills among university STEM students (Md-Ali & Khor, 2018). Over four weeks, the experimental group engaged in 2D/3D geometry exercises with GeoGebra (such as manipulating and problem-solving with interactive visuals), while the control group followed traditional methods. The GeoGebra group recorded a statistically significant improvement in spatial-ability tests, whereas no significant changes were observed in the control group (Suparman et al., 2024).

The European project AuthOMath (2021–2023) offers a multinational perspective on the implementation of automated feedback in Mathematics Education. Rather than a dedicated research study, it was a development initiative that brought together specialists and teachers to create software integrations for adaptive learning. As a result, the project produced an authoring tool that combines GeoGebra applets with STACK (a system for automatic assessment in Mathematics), delivering randomly parameterised questions with multi-step feedback (Pinkernell et al., 2023). The logic is that GeoGebra offers rich interaction (e.g. manipulable graphs and dynamic constructions), while STACK provides a robust engine for algebraic answer checking and adaptive feedback. Early project reports indicate that participating teachers (from Germany, Austria, Spain, and the United Kingdom) appreciated the ability to reuse and customise task templates, and they noted improvements in students' accuracy and persistence when using tasks that combine GeoGebra and STACK (Pinkernell et al., 2023).

In terms of student outcomes, research conducted in various contexts highlights a tendency towards increased engagement and motivation when using game-like Mathematics activities with immediate feedback. A joint study in Italy and the United Kingdom (Inventado et al., 2017) identified "feedback design patterns" that proved effective in online learning systems, such as providing incremental hints, prompting reflective questions after errors, and acknowledging partial correctness. These patterns appear in GeoGebra tasks created by teachers in Lusophone projects—for instance, adding an encouraging message for a correct intermediate step even if the final answer is not yet correct, or suggesting that the student revisit a particular aspect of their reasoning (Abar et al., 2024).

From a robotics education perspective, cultivating persistence and resilience in problem-solving is highly desirable. Robotics often involves processes of trial-and-error and code debugging; familiarising students with Mathematics problems mediated by feedback can transfer that mindset to problem-solving in robotics programming.

In summary, international literature generally corroborates what has been observed in Brazil, Portugal, and Cape Verde: automatic feedback in software such as GeoGebra can significantly enhance core competencies (spatial reasoning, analytical thinking, self-regulation) and boost student engagement. However, it also underscores the continuing importance of teachers. Technology on its own does not bring automatic improvements to learning; it is effective when teachers know how to integrate it into their pedagogical practice. The examples studied show that these professionals take on new roles as designers of digital tasks and facilitators of student-centred learning—roles that demand training and time. This is particularly relevant for forging connections with robotics and other interdisciplinary applications, in which teachers must highlight how the mathematical concepts practised (e.g. coordinates, functions, logical reasoning) relate to robotics problems (such as navigation, sensor-data interpretation, and programming logic).

METHODOLOGY

This study's methodology had two main components. First, the literature review followed a systematic approach to identify and analyse relevant studies in Lusophone countries (Brazil, Portugal, Cape Verde) and around the world. The process began with searches in databases such as Scopus, Web of Science, and Google Scholar, using keywords including "GeoGebra," "automatic feedback," "mathematics education," "teacher," "Brazil," "Portugal," "Cape Verde," and "robotics skills." Boolean operators and truncations were used to capture variations (for example, "automatic feedback" OR "automated feedback"; "robotics" OR "STEM skills"). The initial search (in early 2025) yielded a broad set of publications, including journal articles, conference proceedings, and project reports (Abar et al., 2022; Pinkernell et al., 2023; Suparman et al., 2024).

Inclusion criteria were then applied to refine the selection. For inclusion, each source had to:

Report empirical results (qualitative or quantitative) or detailed project outcomes related to GeoGebra tasks featuring some form of automatic feedback in Mathematics Education (Md-Ali & Khor, 2018; Pinkernell et al., 2023).

Involve teachers or discuss teacher perspectives, especially in the focus countries (Brazil, Portugal, Cape Verde) (Abar et al., 2024; Veber et al., 2022).

Address implications for developing robotics- or STEM-related skills, whether by directly measuring such skills or exploring areas such as problem-solving, spatial reasoning, or computational thinking (Suparman et al., 2024; Veber et al., 2022).

The review prioritised publications from 2015 onwards to capture the most recent developments, though earlier works on feedback and GeoGebra were consulted to establish a theoretical framework. After titles and abstracts were screened for relevance, around 20 sources were selected for full-text review.

During full-text analysis, data were extracted and coded according to key themes: context and participants (e.g. teacher training in Brazil, secondary-level implementation in Portugal), task design in GeoGebra (nature of automatic feedback, subject content, use of gamification), outcomes for teachers (changes in practice, challenges, teacher reflections), and outcomes for students (learning improvements, engagement, skill development). For the specific studies in Brazil, Portugal, and Cape Verde, the focus was on obtaining details from teachers' experiences, often through qualitative data such as interviews or teacher testimonies (Abar & Silva, 2024). Comparative data from other countries were coded to identify commonalities or divergences—for instance, whether challenges in adopting automatic feedback were similarly reported in other regions, or whether parallel effects were observed in student performance.

Where possible, triangulation was used to ensure reliability. If multiple sources addressed the same project (e.g. a conference presentation and a journal article by the same authors), information was reconciled to produce a consistent understanding (Abar et al., 2024). Preliminary summaries were drafted for each thematic part of the literature review (benefits of feedback, using GeoGebra, teachers' experiences, etc.) and revised to confirm that statements were well-grounded in the cited studies. References were managed in Zotero, ensuring correct acknowledgement of the original authors, either through direct quotes or paraphrasing, adhering to APA (7th ed.) guidelines. Because this analysis was based on the literature, no specific ethical approval was required; however, academic integrity was preserved throughout by attributing credit properly.

Second, this study adopted a qualitative case-study approach by focusing on four Mathematics teachers who participated in a professional-development initiative on GeoGebra-assisted learning. The participants were one teacher from Brazil, one from Portugal, and two from Cape Verde, all of whom created and implemented GeoGebra tasks with automatic feedback in their classrooms. With participants' consent, data collection methods included semi-structured interviews, observations during training sessions, and analysis of students' performance in GeoGebra tasks. A thematic analysis was used to identify key patterns in teachers' experiences, student motivation and engagement, and robotics-related skill development.

RESULTS OF THE LITERATURE REVIEW ANALYSIS

The literature review highlights various conclusions regarding GeoGebra tasks with automatic feedback and their role in Mathematics Education and in shaping robotics competencies.

Improved Student Learning Outcomes

In numerous studies, introducing GeoGebra tasks with automated feedback correlates with improved student performance in Mathematics. For example, in Brazil, Abar and Silva (2024) conducted a classroom trial with ninth graders covering linear functions and found that students were able to solve many tasks and progress at their own pace, thanks to the system's guidance and corrective prompts. Students lacking prior knowledge succeeded in catching up through the system's hints, illustrating the effectiveness of guided discovery.

Internationally, quantitative findings echo these results. Md-Ali and Khor (2018) observed significant improvements in geometry test scores within a group using GeoGebra's interactive tools, whereas the control group did not exhibit notable changes. Overall, tasks with automated feedback appear to bolster students' mathematical learning by providing immediate remediation and keeping them actively engaged in problem-solving, preventing them from becoming discouraged by initial difficulties.

Development of Robotics-Relevant Competencies

A central question of this review was whether the skills promoted in these Mathematics tasks translate into robotics. The literature suggests a positive relationship, especially via intermediate competencies. One of the most robust findings involves the impact on spatial visualisation—crucial in robotics for tasks such as design, navigation, and motion planning. Suparman et al. (2024) provide strong meta-analytic evidence that students in GeoGebra-assisted geometry classes improved on average, by more than one standard deviation in spatial-visualisation abilities compared to control groups.

Another relevant aspect is computational thinking and problem-solving. Several of the GeoGebra tasks examined (particularly those featuring game elements or multi-step problem scenarios) implicitly train students in problem decomposition, hypothesis testing, and iteration—core elements of computational thinking. Teachers in Lusophone projects have noted that, over time, students learn to identify and correct their own errors; for instance, after several cycles of feedback, a student working on fractions might start simplifying results on their own, anticipating the software's alert (Abar et al., 2022).

Teachers' Professional Growth and Challenges

Teachers' experiences in Brazil, Portugal, and Cape Verde emphasise significant professional-development gains. Those designing automated-feedback tasks in GeoGebra deepen not only their understanding of the mathematical content but also of students' misconceptions. Predicting various kinds of mistakes in solving equations, for instance, broadens teachers' pedagogical content knowledge (Abar et al., 2024). In the classroom, many teachers describe a shift from being "transmitters" to becoming "facilitators.".

Nonetheless, the literature clearly notes persistent challenges. In Brazil, several teachers withdrew or encountered difficulties arising from the "learning curve" required to master advanced GeoGebra features (e.g. conditional scripting) (Abar et al., 2022). A lack of time and insufficient institutional support also emerged as barriers, since creating high-quality automated-feedback tasks is time-intensive and often not recognised in teachers' workload. In Cape Verde, infrastructural constraints—such as limited internet access and computer availability—were noted as prerequisites for employing GeoGebra in the classroom. Despite these hurdles, the fact that teachers from three countries managed to collaborate and produce operational resources is itself a positive outcome.

Student Engagement and Motivation

The review indicates a rise in student engagement when using interactive tasks. Teachers routinely report heightened concentration and enthusiasm in GeoGebra-based lessons compared to traditional classes. In Portugal, one teacher remarked that students perceived function exercises "like a puzzle or challenge to solve," persistently trying to enhance their performance; previously, they might have given up upon encountering initial difficulty.

Crucially, motivation persists despite challenges—automatic hints prompt students to keep trying rather than abandon the task. Some publications report indirect evidence of engagement, such as reduced absenteeism on days when computers are used or students asking for access to GeoGebra tasks at home for extra practice. In robotics education, maintaining motivation is vital, given the time-consuming nature of building and programming robots. It is encouraging to observe that the same perseverance and resilience in mathematical problem-solving seen in GeoGebra might transfer to robotics programming contexts.

International Comparisons – Common Themes and Differences

Comparing Lusophone experiences with those elsewhere reveals certain universal aspects. The positive impact on learning and skill development is consistently highlighted—whether in Europe, Asia, or the Americas, students appear to benefit from GeoGebra with automated feedback, provided it is implemented thoughtfully.

One notable difference concerns the scale and integration of such practices. In some countries, automated Mathematics assessment is already embedded in large-scale systems (e.g. online homework platforms used by thousands of students daily). In Brazil, Portugal, and Cape Verde, practices are more localised, rooted in innovations by relatively small teacher groups. As such, literature in these countries tends to offer rich qualitative descriptions (teacher reflections, classroom accounts), while contexts with broader adoption often rely on large-scale data (test outcomes, usage statistics). Taken together, these approaches confirm that adopting automatic feedback in GeoGebra strengthens links between Mathematics Education and the competencies required in robotics and other STEM fields.

Regarding the second objective of this study, preliminary findings indicate that implementing GeoGebra tasks with automated feedback markedly enhanced students' computational thinking skills. Teachers report increased engagement and motivation, particularly in tasks requiring iterative problem-solving. In Cape Verde, where access to robotics kits is limited, GeoGebra provided a valuable digital platform to introduce algorithmic reasoning without the need for physical robotic components. The teacher in Brazil observed that students who worked on GeoGebra feedback tasks displayed gains in logical reasoning, aligned with fundamental robotics programming skills. In Portugal, the participating teacher noted that GeoGebra's automated feedback system led to deeper conceptual understanding by enabling students to correct their mistakes independently before tackling more complex problems.

RESULTS OF THE RESEARCH PROJECT

In the present investigation, we analysed empirical data from four teachers who participated in the Project. Participants A1 and A2 are from an African country and are pre-service teachers; participant B is from a South American country, and participant C is from a European country. Participants B and C collaborated online. All these countries share the same official language. In Country A, computational thinking is not part of the official curriculum. In Countries B and C, computational thinking is included in the curriculum: in Country B, it appears within the general Basic and Secondary Education curriculum; in Country C, it is specifically incorporated into the mathematics curriculum for Basic and Secondary Education.

The participants' reports revealed correlations between automated feedback (without direct teacher intervention) in GeoGebra activities and elements of robotic programming.

Participants A1 and A2: Teachers in Country A

Participants A1 and A2, pre-service teachers in Country A, used tasks with automated GeoGebra feedback, even though there is no official curriculum requirement for computational thinking. Their reports show that these tasks involved algorithmic reasoning and error-handling techniques, paralleling debugging processes in robotics.

A1's experience with derivative tasks showed that if students entered incorrect slope values, text messages suggested modifications, steering them towards successive attempts. This cycle of error detection and correction mirrors the debugging process in robot programming (Santos et al., 2024). Likewise, A2 pointed out that tasks involving trigonometric functions required students to input radian values for sine and cosine, with incremental guidance prompting adjustments—akin to the "fine-tuning" of robotic movement programming.

A further noteworthy observation related to integral tasks, where the software flagged potential discontinuities in a way that resembled obstacle-detection mechanisms in robotics. These scenarios illustrate how GeoGebra fosters computational thinking in contexts where it is not formally required, while simultaneously preparing teachers for structured, algorithmic problem-solving practices.

Participant B: Teacher in Country B

In Country B, where computational thinking features in the Basic and Secondary curriculum, teacher B's efforts centred on tasks involving data validation, rule-based feedback, and iterative problem-solving—elements consistent with robot programming.

An exponential functions task demonstrated rule-based debugging, where incorrect data entry in a table triggered revision prompts, reinforcing validation practices like debugging robotic systems (Gaur & Kalita, 2024). Additionally, tasks in graphical representation revealed that correct numerical inputs dynamically updated function curves—an approach analogous to modelling robotic trajectories, in which movement parameters are iteratively adjusted.

A crucial finding was the increased student motivation: participant B noted that incremental challenges in the feedback system fostered perseverance, like robotics competitions, where stage-by-stage progression sustains motivation and cognitive engagement (Varghese et al., 2025).

Participant C: Teacher in Country C

In Country C, where computational thinking is embedded in the mathematics curriculum for Basic and Secondary Education, participant C's experiences largely paralleled those of participant B, particularly concerning the computational structure of tasks.

The exponential functions task, for instance, demonstrated how progressive feedback loops ensure that students refine their understanding via corrective guidance. When a student input an incorrect function value, the system highlighted discrepancies and prompted conceptual reviews—akin to code review in robotics (Hamed, Wong & Khambari, 2025).

Participant C further emphasised how real-time graphical modelling with immediate feedback enables students to see the direct relationship between input and output, strengthening pattern recognition and modelling skills—vital in developing AI models in robotics (Ugolini & Kakavas, 2024).

Cross-Country Analysis: Common Themes and Differences

In all cases, GeoGebra tasks with automated feedback fostered computational thinking, robotics-related problem-solving, and algorithmic reasoning. Differences also arose:

In Country A, which does not formally mandate computational thinking, teachers created tasks with robotics-like logic. This suggests that GeoGebra can act as an implicit tool for robotics education, even in contexts lacking specific policy support.

In Countries B and C, where computational thinking is compulsory, tasks were explicitly structured around algorithmic flows, conditional branching, and debugging processes, making the connection between Mathematics and robotics direct.

In these same countries (B and C), participants reported deeper student engagement thanks to challenge progression—a form of gamification reminiscent of robotics competitions.

DISCUSSION

The studies reviewed show that Mathematics teaching enriched by GeoGebra tasks featuring automated feedback can reinforce teachers' and students' robotics-related skills. Both Mathematics and robotics demand spatial reasoning and procedural thinking; GeoGebra tasks promote systematic problem-solving and structured error-handling. Teachers who design these tasks, anticipating students' difficulties and embedding corrective guidance, replicate fundamental debugging principles, essential in robot programming (Suparman et al., 2024). Through this design process, educators achieve deeper subject understanding and foster algorithmic reasoning that can be transferred to robotics challenges.

Teachers in Brazil, Portugal, and Cape Verde indicated that innovation depends on collaboration networks, institutional support, and time for mastering new tools (Abar et al., 2022). International communities of practice offer opportunities to share resources and strategies, reducing the isolation that may occur in digital initiatives. Such networks also encourage the creation of contextualised materials that align with diverse curricula. This resonates with the TPACK model, which emphasises the interplay of technological, pedagogical, and content knowledge (Abar et al., 2024).

Research in multiple contexts shows that automated-feedback systems can raise motivation and problem-solving abilities, transforming abstract concepts into dynamic learning experiences (Md-Ali & Khor, 2018; Pinkernell, et al., 2023). Traditional assessments may not fully capture dimensions such as creativity and spatial awareness; however, longer-term analyses may reveal how these activities affect students' STEM trajectories. For policymakers aiming to develop robotics skills, integrating GeoGebra tasks into Mathematics curricula emerges as a possible strategy to develop spatial reasoning and algorithmic thinking without relying on physical robotics kits.

These approaches uphold the teacher's pedagogical role, highlighting its centrality in designing interactive tasks. Data from various projects show that incorporating aspects of intelligent tutoring systems—guided by teacher expertise—allows merging the benefits of automated systems with the teacher's ability to tailor content to students' needs (Veber, et al., 2022). The main challenge lies in disparities in hardware access. Future research might examine the extent to which using shared devices or mobile labs affects the long-term development of computational thinking and readiness for robotics.

Empirical data from the Lusophone Project strengthen the theoretical standpoint that teachers, in designing GeoGebra tasks, internalise programming principles comparable to those in robotics. By planning feedback for predictable errors, they adopt a mindset of debugging, rule-based logic, and incremental refinements (De la Hoz Serrano & Melo Niño, 2024). Even in education systems without explicit computational-thinking policies, using digital tools can lead to computational practices. In countries with such policies, the link to robotics is straightforward, and teachers produce tasks that highlight algorithmic flows, conditionals, and debugging consistent with curriculum requirements.

Continuous teacher training thus emerges as a decisive factor. In Country A, the absence of formal requirements did not hinder the emergence of algorithmic practices, whereas in Countries B and C, the curricular framework supported more systematic adoption of tasks that develop computational thinking. In either scenario, professional development that combines GeoGebra exploration with robotics-related examples appears to enhance teacher confidence and student engagement (Sadik & Budiyanto, 2024).

Taken as a whole, the evidence confirms that GeoGebra tasks with automated feedback provide a bridge between Mathematics Education and the development of robotics skills. Students gain experience in experimentation, error analysis, and iterative problem-solving—core elements in robot programming. Meanwhile, teachers enhance their pedagogical and technological capabilities, playing a pivotal role in linking mathematical concepts to robotic programming challenges. These findings align with Varghese et al. (2025), who argue that interactive digital environments nurture resilience and adaptive thinking, equipping learners to tackle future technological problems.

Policy-wise, these insights suggest that folding computational competencies into Mathematics curricula can be implemented using digital tasks, minimising the gap between Mathematics and Programming. Equipping teachers with the skills to build feedback-centric digital tasks leads to computational fluency and adaptive problem-solving. Although national policies on computational thinking vary, the study shows that teacher initiative and adequate professional development opportunities are key to aligning robotics with Mathematics Education (López-Bouzas & Castañeda Fernández, 2024).

CONCLUDING REMARKS

This literature review examined how automated-feedback tasks in GeoGebra intersect with robotics-related skills in Mathematics Education, focusing on teacher-led initiatives in Brazil, Portugal, and Cape Verde, supplemented by international comparisons. The findings suggest that automated and adaptive feedback improves student learning outcomes and fosters spatial visualisation, logical reasoning, and perseverance in problem-solving (Md-Ali & Khor, 2018; Suparman et al., 2024). These competencies lie at the heart of Mathematics and are readily transferable to the requirements of robotics and other STEM domains. By combining GeoGebra with structured feedback, mathematics lessons can empower students to develop experimentation habits, error-detection skills, and logical reasoning via multiple representations—thus aligning with the demands of robotic programming and technology design (Pinkernell et al., 2023).

Experiences in Brazil, Portugal, and Cape Verde highlight both the potential and the conditions needed for implementing GeoGebra tasks with automated feedback. Teachers in these countries reported enhanced student engagement, richer problem-solving experiences, and professional growth as they took on the role of "content designers" (Abar et al., 2022, 2024). One transnational project in these regions resulted in shareable and adaptable interactive activities, supporting a community of innovative educators. Nonetheless, it is also clear that investment in teacher training, allocated time, and collaborative support is necessary (Abar & Silva, 2024). Successfully adopting digital innovations in the classroom requires sustained institutional backing.

Comparisons with research in Asia, Europe, and the Americas support the educational benefits of immediate feedback and interactive visualisation in Mathematics (Pinkernell et al., 2023; Suparman et al., 2024). Research from Lusophone nations adds the teacher's viewpoint: successful innovations rest heavily on educators' knowledge and drive, and the successes and obstacles they experience point to the necessity for ongoing professional-development structures that instil confidence in using advanced tools.

The data confirm that designing GeoGebra tasks with automated feedback encourages both teachers and students to adopt computational thinking and robotics skills. Empirical observations, coupled with theoretical explorations, illustrate that digital learning tools can bridge Mathematics and computer science, strengthening algorithmic reasoning, structured iteration, and problem-solving. Embedding feedback mechanisms in mathematics tasks mirrors essential practices in robotics programming, such as debugging, parameter calibration, and data-driven decision-making. Teachers creating these tasks engage in processes like software development in robotics, applying conditional logic, handling errors, and refining through feedback loops.

For students, iterative processes stimulated by GeoGebra develop persistence in problem-solving, real-time error detection, and logical thinking—all indispensable in robotics, engineering, and computational fields. Reports from teachers in Countries B and C underscore the motivational boost when tasks are framed as progressive challenges, reflecting the phased or competitive style found in robotics (Hamed et al., 2025).

From the perspectives of teacher training, curriculum development, and policymaking, the findings suggest that computational thinking may be woven into Mathematics Education through digital tasks, reducing the division between Mathematics and Programming. Professional-development activities that enable educators to create digital tasks with a feedback focus foster computational fluency and flexible problem-solving. While each country's curriculum treats computational thinking differently, the study shows that teacher initiative and professional-development opportunities are decisive in merging robotics with Mathematics Education (López-Bouzas & Castañeda Fernández, 2024).

GeoGebra-based learning environments demonstrate the evolving role of technology in STEM Education. As Mathematics teaching embraces digital and algorithmic methods, the boundaries between traditional problem-solving and computer science become increasingly permeable. The evidence here shows that digital feedback systems nurture algorithmic reasoning and iterative improvement—attributes central to robotics, artificial intelligence, and data analysis (Sadik & Budiyanto, 2024). Further research would profit from longitudinal tracking of students to determine whether such competencies translate into tangible outcomes in robotics projects and encourage more positive attitudes towards STEM.

In sum, GeoGebra tasks with automated feedback serve as a bridge between Mathematics Education and robotics skills, providing a framework for critical thinking, structured error detection, and collaborative problem-solving. These findings indicate that curricula and educational policies should view interactive digital tools as core elements of STEM programmes. By enabling teachers to design feedback-focused tasks, education systems reinforce computational literacy and flexible thinking among students, preparing them for challenges in robotics, engineering, and related scientific fields. GeoGebra does not replace physical robotics resources but complements them, fostering essential skills for robotics and other computational domains (Abar & Silva, 2024). The prospect of classrooms in which students engage in creative exploration guided by immediate feedback is promising for shaping future innovators capable of dealing with constantly evolving technological challenges. Follow-up studies might investigate more closely whether these skills persist and enhance student progression in computational and engineering pathways.

AUTHORS' CONTRIBUTIONS STATEMENTS

CAAP and JMDSDS participated in all phases of research development: preparation, participation in remote meetings and data collection.

CAAP, JMDSDS, AMRAB and ZL actively participated in the discussions and reviewed and approved the final version of this work.

DATA AVAILABILITY STATEMENT

Data supporting the results of this study will be made available by the authors for correspondence, upon reasonable request.

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