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Innovative STEM-Excel Integration to Foster Students' Mathematical Representation Skills

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ABSTRACT

Mathematical representation ability (MRA) is essential to mathematics learning, yet many high school students struggle with topics such as quadratic equations and functions. This study aims to develop and evaluate an Excel spreadsheet–based learning media integrated with a STEM (Science, Technology, Engineering, Mathematics) approach to enhance students' MRA. Using the Research and Development (R&D) method with the ADDIE model (Analysis, Design, Development, Implementation, Evaluation), the media was tested on 32 tenth-grade students at SMA Negeri 1 Samalanga. Data were collected through expert validation, teacher and student questionnaires, and pretest-posttest MRA instruments. The results showed that the media achieved high validity (89.25%), was rated very practical by teachers (83.2%) and students (87.3%), and significantly improved students' MRA, with an N-Gain score of 0.75 (high category). Thus, the Excel-STEM learning media is valid, practical, and effective in improving students' mathematical representation skills. This study contributes to the field of educational technology by offering a low-cost, accessible, and pedagogically sound digital tool that integrates STEM principles into mathematics instruction, supporting the development of representational fluency in secondary education.

ARTICLE INFORMATION

Keywords:
ADDIE Model; Excel Spreadsheet; Mathematical Representation Ability; Quadratic Equations; STEM Education

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INTRODUCTION

Mathematical representation ability (MRA) is a fundamental component of mathematics learning, as it enables students to understand, communicate, and solve problems through various forms of verbal, symbolic, and visual representations (Goldin & Stylianou, 2020). However, this competency remains underdeveloped among Indonesian high school students, as evidenced by national and local data. Internationally, Indonesia's numeracy performance remains low, with a PISA 2022 score of 383, reflecting a decline of 13 points since 2018 (OECD, 2022). Nationally, the 2024 Education Report indicates that only 41.14% of senior high school students met the minimum competency in numeracy, an indicator closely linked to MRA (Kemdikbud, 2024). Preliminary observations and teacher interviews at SMA Negeri 1 Samalanga further confirm this issue, revealing that students struggle particularly with translating quadratic equation problems into graphical, symbolic, and verbal representations. These difficulties are compounded by limited access to interactive, technology-based learning tools that can visually demonstrate mathematical concepts.

Therefore, developing an accessible, technology-integrated learning media that bridges representational gaps is both urgent and pedagogically significant. Numerous studies have developed digital learning media to enhance students' MRA. GeoGebra is effective in strengthening mathematical representations (Septian et al., 2023), while spreadsheet-based media have demonstrated their potential to improve conceptual understanding through data visualization and simulation (Chusna, 2022; Zulfira et al., 2024). Meanwhile, the STEM approach has been proven to enhance mathematical literacy and 21st-century skills by situating learning in real-world contexts (Khairiyah, 2019; Priyadi & Kuswanto, 2023). Nevertheless, most existing STEM-based media rely on specialized software such as iSpring or Articulate Storyline (Rahmawati et al., 2021), which require stable internet access and relatively advanced technical skills. A review of the literature reveals a research gap: a lack of studies that explicitly integrate easily accessible, offline-capable, and widely used Excel spreadsheets with a STEM approach to enhance students' MRA, particularly in quadratic equations and functions.

In practice, students often struggle to visually and symbolically represent quadratic concepts, such as drawing graphs or constructing mathematical models from real-life contexts (Yuhasriati et al., 2022; Abdurahman, 2023). Teachers also tend to employ manual instructional methods that are inefficient and less interactive (Tarigan et al., 2023; Siregar et al., 2022). Based on these conditions, the main problem addressed in this study is the low level of students' MRA due to the limited availability of contextual, interactive, and easily accessible learning media. As a solution, this study develops an Excel spreadsheet–based learning medium integrated with an embedded STEM approach, in which mathematics serves as the primary focus, while science, technology, and engineering function as contextual supports. The media are designed to be interactive, incorporating dynamic simulations, graphical visualizations, and real-world context–based exercises to stimulate verbal, symbolic, and visual mathematical representations. The purpose of this study is to produce an Excel spreadsheet–based learning medium integrated with a STEM approach that is valid, practical, and effective in improving students' MRA on quadratic equations and functions. Validity is evaluated through expert judgment, practicality is measured through teacher and student responses, and effectiveness is assessed based on improvements in students' MRA scores using a one-group pretest–posttest design.

METHOD

This research adopts a Research and Development (R&D) methodology using the ADDIE model, comprising five systematic phases: Analysis, Design, Development, Implementation, and Evaluation (Sugiyono, 2022). The analysis phase involved a needs assessment conducted through interviews with teachers and students, as well as a review of curriculum documents. The design stage focused on developing STEM-based Excel learning media and instructional modules aligned with indicators of Mathematical Representation Ability (MRA). The development stage involved creating a media prototype using Microsoft Excel and Visual Basic for Applications (VBA).

This study employed the Research and Development (R&D) approach using the ADDIE model, comprising five stages: Analysis, Design, Development, Implementation, and Evaluation. During the development stage, a learning media prototype was created in Microsoft Excel and Visual Basic for Applications (VBA), specifically designed to integrate STEM principles and support multiple mathematical representations. During implementation, the media were tested across five instructional sessions in a classroom setting, after which their validity, practicality, and effectiveness were thoroughly evaluated. The research subjects consisted of 32 tenth-grade students from class X-2 at SMA Negeri 1 Samalanga, selected through purposive sampling based on homogeneity in academic background and access to classroom technology. Conducted during the second semester of the 2024/2025 academic year, the study focused on quadratic equations and functions, with

particular emphasis on developing students' visual, symbolic, and verbal representational skills through structured learning activities embedded in media.

The research instruments included expert validation sheets covering aspects of content, media design, and interactivity, reviewed by two validators—a mathematics education expert and a media expert. Additionally, teacher and student response questionnaires were administered on a 4-point Likert scale (1 = strongly disagree to 4 = strongly agree) to assess the perceived practicality of the media. Students' MRA was assessed using a five-item essay test measuring visual, symbolic, and verbal representational abilities.

All instruments underwent content validation by experts and were empirically tested on 10 students outside the main sample to ensure reliability and appropriateness. Data analysis was conducted through a mixed-method approach: validation and questionnaire data were analyzed descriptively using percentage techniques, with scores ≥81% categorized as very valid or practical. Qualitative data from semi-structured interviews with teachers and students were processed using NVivo 12 Plus, including open coding, node creation, and thematic visualization through node relationship diagrams. The resulting themes were used to triangulate methods and reinforce and deepen the interpretation of quantitative findings, thereby enhancing the validity and comprehensiveness of the research outcomes.

RESULTS AND DISCUSSION

The development process in this study followed the five-stage ADDIE model—analysis, design, development, implementation, and evaluation. The study's outcomes are elaborated in the sections below. The analysis phase of this study identified a fundamental pedagogical challenge: students' persistent difficulty in expressing mathematical ideas, particularly regarding quadratic equations and functions, through the integrated use of visual, symbolic, and verbal representations (Santia et al., 2019; Novitasari et al., 2021; Yuhasriati et al., 2022). Weakness in translation between representations (verbal → symbolic, symbolic ↔ graphic) clearly hinders conceptual understanding and problem-solving (Rahmawati et al., 2025). Students with low self-efficacy tend to rely only on verbal representations and struggle with visual and symbolic representations of quadratic functions (Hasyari et al., 2025). Low mathematical representation ability (verbal, visual, symbolic) limits how students interpret problems and express solution ideas, reducing problem-solving success and conceptual understanding (Dahiana et al., 2023; Utami et al., 2024; Rif'at & Imama, 2024). Many students struggle to shift between forms (e.g., graphs, equations, context), leaving answers incomplete or purely procedural (Dahiana et al., 2023; Utami et al., 2024). Traditional graph plotting is typically teacher-centered, pen-and-paper-based, and can be monotonous and demanding in terms of accuracy and time, thereby reducing engagement (Iroriteraye-Adjekpovu & Nwabuaku, 2024; Umah & Rahmawati, 2024). Therefore, the core problem was defined as the lack of a contextual, technology-mediated learning medium capable of bridging multiple representational modes. This diagnostic stage established a clear imperative for developing an interactive digital resource that could make mathematical concepts more tangible and explorable for learners.

The Independent Curriculum emphasizes flexibility, differentiated learning, character building through the Pancasila Student Profile, and focuses on literacy and numeracy as essential competencies (Azmi et al., 2023; Fathimah et al., 2025; Ronel et al., 2025). The learning outcomes for Phase E are formulated as a narrative of attitudinal, knowledge, and skill competencies tailored to the developmental stage of tenth-grade students, with a coherent progression of learning objectives throughout the phase (Amalia & Achadi, 2023; Magdalena et al., 2023; Danapong, 2025). By grounding the development in the official curriculum framework, the study ensured the resulting media's direct relevance and immediate applicability in authentic classroom settings. Thus, the analysis phase

successfully synthesized pedagogical gaps, user needs, and curricular mandates into a coherent foundation for the subsequent design of the STEM-integrated Excel learning media.

Table 1. Expert validation results of the STEM-based Excel learning media

Assessment Aspects	(%)	Category
Suitability of the material with the curriculum	92.5	Very Valid
Accuracy of mathematical concepts	95.0	Very Valid
STEM Integration	87.5	Very Valid
Visual quality and navigation	88.0	Very Valid
Interactivity & feedback	84.0	Very Valid
Overall average	89.25	Very Valid

The practicality of the media was evaluated through post-implementation questionnaires administered to one teacher (n = 1) and 32 students (n = 32). The teacher awarded a score of 83.2, categorized as *very positive*, while the average student response reached 87.3, also classified as *very positive* (Vlachogianni & Tselios, 2021; Vlachogianni & Tselios, 2023; Rebollo & De Oliveira, 2023) (Table 2). Students reported that the media helped them "more easily understand the relationship between formulas and graphs" and that they were "no longer afraid of drawing parabolas." The teacher indicated that the media was "easy to integrate into both online and offline learning" and "reduced the burden of explaining abstract concepts." These findings confirm that the media is not only theoretically valid but also practical for use in authentic classroom contexts.

Table 2. User response categories to media

Respondents	Average Score	Index (%)	Category
Teachers'	83.2	83.20	Very Good
Students'	87.3	87.30	Very Good

The effectiveness of the developed media was evaluated using a one-group pretest–posttest design to assess students' Mathematical Representation Ability (MRA). The mean pretest score was 32.5, which increased significantly to 71.8 in the posttest. Normalized gain analysis produced a value of g = 0.75, which is classified as high according to the categorization proposed by Meltzer (2002) and widely adopted in recent mathematics and science education research (Coletta & Steinert, 2020) (Figure 1). The most substantial improvements were observed in the indicators related to interpreting graphs and constructing mathematical models from real-world problems. The simulation and case study directly supported these gains, which are embedded in the media. The results empirically demonstrate that the developed media effectively enhances students' MRA and support the initial hypothesis that integrating Excel with a STEM approach can strengthen mathematical representation through dynamic and contextual exploration.

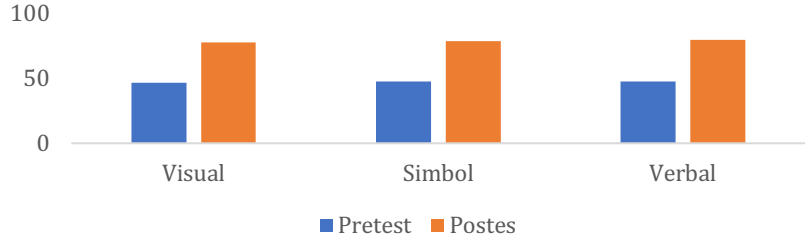

Figure 1. Comparison of MRA pretest and posttest scores of students' mathematical representation ability

The qualitative analysis of semi-structured interviews, conducted in NVivo 12 Plus using open coding and thematic clustering, yielded rich insights into the intervention's impact. The node relationship diagrams revealed six interconnected central themes. First, both teachers and students reported a marked increase in student activeness and participation during lessons. This engagement was closely linked to a deeper, improved conceptual understanding of quadratic functions, facilitated by the media's interactive visualizations. Consequently, observers noted positive changes in learning attitudes, with students displaying greater curiosity and perseverance. This shift in the learning dynamic also redefined the teacher's role as a facilitator, guiding exploration rather than delivering direct instruction. A strong interest in the STEM-based Excel media was evident, with students appreciating its practical, relatable design. Finally, these elements collectively fostered greater learning autonomy, enabling students to manipulate variables, test hypotheses, and explore concepts at their own pace. The diagram illustrates that the "Interview Results Table" functions as a central node connecting all identified themes. This interconnected structure indicates that media use has a holistic impact, extending beyond cognitive gains to influence the affective and metacognitive dimensions of learning positively.

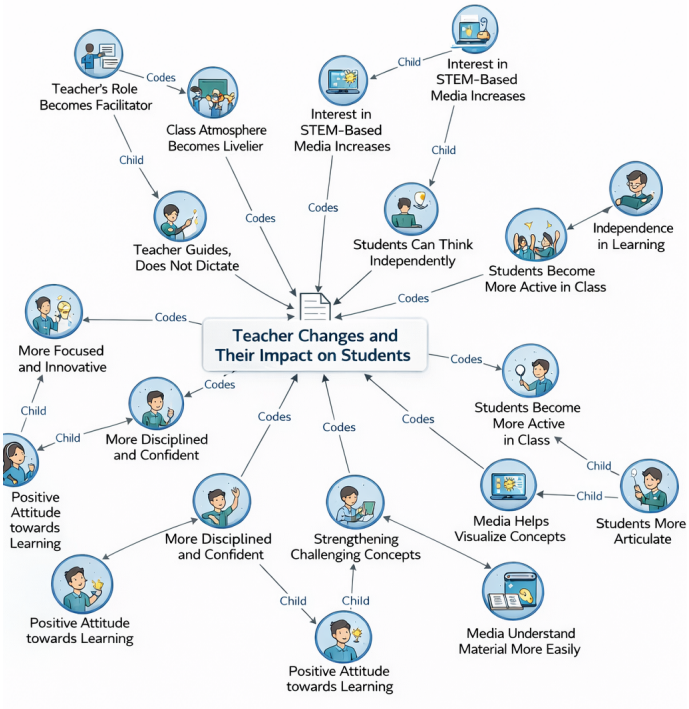

Figure 2. NVivo visualization of thematic relationships in teachers' and students' Experiences with STEM-Based Excel Media

The primary factors contributing to the success of the developed media lie in the integration of three key elements: 1) the use of widely available and easy-to-operate technology (Excel); 2) an embedded STEM approach that provides contextual meaning to abstract mathematical concepts, and; 3) a multiple-representation–based design (Cirneanu & Moldoveanu, 2024). Excel-based modeling in science and engineering has been shown to simplify complex calculations, support real-time exploration, and significantly improve conceptual understanding and engagement compared with traditional instruction (Onwukwe et al., 2025). STEM-integrated multimedia and curricula that connect mathematics to real-world, problem-based STEM contexts are consistently rated as valid, practical, and very good by both experts and students, improving data/technology literacy and motivation (Ahzari & Asrizal, 2023). Meta-analytic work on contextual and multi-context approaches

in mathematics reports a substantial positive effect on mathematical achievement (overall effect size ≈ 0.65), especially when mathematics is tied to technology and realistic applications (Putri et al., 2025), which explicitly stimulate visual, symbolic, and verbal representations. The dynamic simulation features enable students to independently test hypotheses (e.g., "If the coefficient is negative, the parabola opens downward"), while the case study activities encourage them to connect mathematical concepts to real-life situations—strategies that are effective in previous studies (Wassie & Zergaw, 2019; Gökçe & Güner, 2022).

One of the main strengths of this study lies in the originality of integrating Excel and a STEM approach to enhance Mathematical Representation Ability (MRA), an integration that has not been identified in the literature over the past decade. Conversely, the principal limitation of this study is the restricted sample size (only one class in a single school) and the relatively short implementation period (five instructional sessions), which limit the generalizability of the findings. Nevertheless, these limitations are mitigated by the depth of qualitative analysis and by the triangulation of data sources (quantitative, qualitative, and classroom observations).

Compared to prior studies, such as Bernard and Senjayawati (2019), who developed VBA-based Excel media to enhance students' mathematical self-confidence, and Zengin (2017), Many studies use GeoGebra primarily to visualize functions or graphs and report gains in understanding, but focus on the visual/technical layer. Training on creating and interpreting algebraic function graphs centers on helping students draw and analyze graphs (intercepts, slope, extrema) with GeoGebra as a visual aid, improving motivation and conceptual grasp of graphs but not systematically targeting other representational forms (Puspita et al., 2025), Experimental work on functions, limits, and trigonometric functions shows GeoGebra improves achievement by enabling dynamic graphical representations and links among multiple views, yet the emphasis is on graph visualization and technical use of the software (Zulnaidi et al., 2019; Mosese & Ogbonnaya, 2021; Bedada & Machaba, 2022). Studies on exponential or complex functions similarly highlight interactive visualization and domain coloring as ways to better "see" the function behavior, again privileging graphical exploration (Tuda & Rexhepi, 2023). Research on mathematical representation stresses that effective learning requires coordinating multiple modes—verbal, algebraic, numeric, and graphic—and supporting translation between them (Mainali, 2020; Putra et al., 2023). These theoretical frameworks of mathematical representation and the core principles of problem-based learning (PBL) are embedded within STEM education (Khairiyah, 2019). This integrated approach is further supported by contemporary perspectives emphasizing the pedagogical value of diverse and interconnected representational modes when mediated by accessible technology (Aloizou et al., 2024)

Theoretically, this study contributes to the evolving body of knowledge on technology integration in mathematics education, particularly regarding the development and orchestration of multiple mathematical representations. From a practical standpoint, the proposed media offers a cost-effective, high-impact solution for senior secondary mathematics teachers seeking to improve students' mathematical representation ability (MRA) without requiring proficiency in specialized software. Given the widespread availability of Microsoft Excel across educational institutions, the tool demonstrates strong ecological validity and scalability. Moreover, the embedded STEM-oriented design enables replication and adaptation to other mathematical domains, including systems of linear equations, trigonometry, and statistical reasoning (Felder & Brent, 2024; Ferguson & Polojac-Chenoweth, 2024). In conclusion, this study not only yields a valid, practical, and effective learning medium, but also advances a reconceptualized perspective within mathematics education: that carefully designed, pedagogically principled use of ubiquitous technologies such as spreadsheet software, when situated within a STEM and problem-based learning framework, can serve as a powerful catalyst for transforming mathematics instruction from predominantly procedural and

memorization-based practices into meaningful, conceptually rich, and exploratory learning experiences (Felder & Brent, 2024).

CONCLUSION

This study successfully developed and validated a Microsoft Excel spreadsheet-based learning media integrated with a STEM approach to enhance students' Mathematical Representation Ability (MRA) in quadratic equations and functions. Based on the research and development process, it can be concluded that the Microsoft Excel spreadsheet-based learning media, integrated with a STEM approach, is valid, practical, and effective in enhancing students' Mathematical Representation Ability (MRA) in quadratic equations and functions. The key results confirm high validity (89.25%), very positive practicality ratings from teachers (83.2) and students (87.3), and significant effectiveness, with a high normalized gain score (0.75). The application of this media demonstrates a meaningful impact by successfully transforming an accessible digital tool into a powerful pedagogical instrument that fosters integrated visual, symbolic, and verbal representations, reduces the abstraction of mathematical concepts, and promotes active, student-centered learning. For broader implementation, it is recommended to expand trials across diverse school contexts, explore integrating adaptive feedback features, and develop accompanying teacher training modules to maximize the media's educational potential.

DECLARATION OF GENERATIVE AI

The authors declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

CONFLICTING INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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