Jurnal Gantang X (1) (2025): 45-52

e-ISSN: 2548-5547
p-ISSN: 2503-0671

http://ojs.umrah.ac.id/index.php/gantang/index

Realistic mathematics for aerospace engineering students: Design research using math mobile apps

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Submission: March 7th 2025; Accepted: May 24th 2025; Published: May 31st 2025
DOI: https://doi.org/10.31629/jg.v10i1.6895

Abstract

The "realistic" concept in Realistic Mathematics Education (RME) is often confined to everyday contexts. In contrast, for aerospace engineering students, realistic mathematics should reflect the mathematical applications in their academic and future professional environments. This study aimed to design and evaluate instructional activities grounded in RME principles, integrating mathematics mobile applications to support conceptual understanding and reasoning. Using a design research approach, the study involved a questionnaire distributed to alums and third-year students, followed by two implementation cycles with first-year aerospace engineering students. The focus was on integral strategies in calculus, utilizing Photomath to bridge informal and formal mathematical reasoning. Results indicate that students engaged actively with the applications and demonstrated improved reasoning skills, particularly in inductive and imitative reasoning. This study highlights the potential of contextualized digital tools in supporting realistic mathematics learning in higher education. It suggests directions for aligning university-level mathematics with its practical applications in other disciplines, such as aerospace engineering.

Keywords: realistic mathematics education; aerospace engineering students, design research; mathematics mobile application; calculus

How to cite: Funny, R, A., Kusumaningrum, M, A, D., & Rahmawati, F, K. Realistic mathematics for aerospace engineering students: Design research using math mobile apps. *Jurnal Gantang*, *10*(1), 45 – 52. https://doi.org/10.31629/jg.v10i1.6895

I. Introduction

The Realistic Mathematics Education (RME) implementation has a significant positive effect on students' mathematical abilities since RME enables them to collaborate, discuss, think, and find solutions to real-world problems (Juandi, Kusumah & Tamur, 2022). The impact of RME on Indonesian students' mathematics abilities also strongly influences their mathematical achievements (Juandi et al., 2022). This superiority of RME is also supported by the previous meta-analysis of game-based learning, which was found effective for math, science, and language for students and college students (Laurens, Batlolona, Batlolona & Leasa, 2018), but the effect size differs. This study found that the average effect size of the studies on universities was smaller than those conducted in primary and secondary. Some studies also support the finding that the RME effect is almost the same as that in primary and secondary schools but differs significantly between universities (Juandi et al., 2022).

A few studies of RME in universities showed that the university students treated with realistic mathematics learning were better than those with conventional methods (Anggraini & Fauzan, 2020; Hr, Sukandi & Dewi, 2021). They also conclude that the application of RME was practical in improving students learning outcomes in visual learning styles, followed by auditory and kinesthetic styles (Hr et al., 2021). Although some studies report positive results, due to a lack of research on RME for universities, it is assumed that RME is not recommended to be implemented at the university level. They argued based on the RME framework, which usually offered students the problem situations they could imagine (Funny, 2014; Heuvel, 1996). Students studying in universities considered no longer need this framework (Juandi et al., 2022), but it still needs further research. The idea of realistic for university students is never more the situations they can imagine; it should be the mathematics used in their workplace (How, 2022). It is caused by the fact that the definition of context in realistic mathematics is comprehensive and flexible. The purpose of learning mathematics in realistic situations is to make students aware of the function of those concepts in their daily lives. Meanwhile, daily for students in the primary will be different from universities.

On the other hand, engineering students still have negative feelings about mathematics (Goold, 2014). This issue persists across various contexts, as recent studies also report that engineering students often perceive mathematics as abstract and disconnected from real-world applications, leading to low motivation and anxiety (Lippert, 2020; Tum, 2024). Furthermore, graduate engineers' difficulty communicating mathematics becomes a significant weakness of engineering education (Goold, 2012), impacting their problem-solving and collaboration skills in professional settings. To address these challenges, there is a growing need for instructional strategies that improve mathematical comprehension and enhance students' attitudes and communication skills. Realistic Mathematics Education (RME), supported by technology such as mobile mathematics applications, offers a promising approach to contextualize learning and make it more meaningful for engineering students.

Therefore, this study will gather information about how students in universities, especially those majoring in aerospace engineering, use mathematics in their schooling and workplace to design learning sequences for the mathematics concepts needed by aerospace engineering and support their mathematics skills using the RME approach.

Mathematics for Aerospace Engineering

The aerospace engineering students still find difficulties learning mathematics at their university. These students could not see the 'general' through the particulars in the general when dealing with mathematical concepts and examples. They could not see the essential features of a technique or recognize them when presented in different forms (Rahman, Yusof & Baharun, 2012). Furthermore, most engineering problems with academic achievements are usually related to the STEM approach since the mindset of engineering is closely related to technology (Cecil, Ramanathan, & Mwavita, 2013; Hafni, Herman, Nurlaelah & Mustikasari, 2020; Ilyas, Meiyani, Ma'rufi & Kaewhanam 2022; Strimel & Grubbs, 2016). It is true, but the technology without the comprehension inside is ineffective. Therefore, it is necessary to have a real-world environment of mathematics that will be used for aerospace engineering.

Meanwhile, technology development is progressing rapidly across all sectors. Accordingly, the International Paris Air Show of 2017 highlighted the growing importance of digital technologies in aeronautical production, particularly mobile technology, cloud computing, big data, social media, and IoT, which have been identified as the Big Five (Martinez-Lopez, 2019). A series of recent studies said that the industry already uses digital technologies to support the human workforce of maintenance engineers specializing in aircraft engines.

On the other hand, the digital technology adoption from education in the aeronautical engineering field is still developing. Some studies indicated that technology does not help much to motivate students in mathematics; the specific technology-based activities that used to increase STEM competence among students only gave modest improvement (Star et al., 2014). Similar findings have been reported in more recent research, suggesting that while digital tools offer potential, their effectiveness heavily depends on how they are integrated into pedagogy (Evtushenko, Toporkova, Kokhashvili & Yankina 2023; Kazu & Yalcin, 2021; Öztop, 2023). The mere presence of technology does not guarantee increased engagement or understanding unless accompanied by meaningful instructional strategies that align with students' learning needs and contexts. A practical guide to increasing engineering students' motivation to learn mathematics is to link mathematics and engineering and show them how important it is to study fundamental mathematics and how to solve real practical problems (Le Clainche, Pérez & Ferrer, 2017; Patil, Rangari, Pawar & Dubey, 2022), which is closely related to the Realistic Mathematics Education (RME) approach.

Realistic Mathematics for Aerospace Engineering Students

Several studies concluded that implementing RME has a significant positive effect on students' mathematical abilities compared to traditional learning (Juandi et al., 2022). Juandi et al, (2022) have conducted meta-analyses in 198 journals and found that RME is most effective with sample sizes less than or equal to 30, with 3–4 sessions, and using mathematical software. Also, the application of RME is not recommended for universities. Why is it so? For university students, mathematics is still required to solve their problems, which may not be daily life problems but workplace problems. The context of the problems becomes the foundation for progressive mathematizing to lead the students to develop their informal strategies into formal solutions by experientially experiencing the realistic situation (Armiati, Permana & Noperta, 2019; Huda & Armiati, 2020; Theodora & Hidayat, 2018). According to the Oxford Dictionary, the word 'realistic' is defined as representing things in a way that is accurate and true to life. Therefore, for higher-education students, the realistic means will differ between primary and secondary. For engineering, the realistic is what it is used and needs in their workplace. This study investigates how university students particularly those majoring in aerospace engineering use mathematics in academic and workplace settings. The insights gained from this investigation serve as the foundation for designing instructional activities that reflect the real demands of the engineering field, making mathematics more meaningful and applicable for aerospace engineering students.

II. Research Method

Realistic Mathematics Education (RME) has five characteristics (Nuraida & Amam, 2019), which are contextualization, use of models, students' construction, interactivity, and linkage that have been widely studied in primary and secondary education, showing a strong positive effect on students' mathematical abilities. This study adapted these characteristics for aerospace engineering students based on analyzing questionnaire responses. The five adapted characteristics include: (i) Contextualization—the integral concept in calculus is recognized as essential for solving real engineering problems; (ii) Use of models—Photomath is employed as a digital bridge between concrete and formal mathematical understanding; (iii) Student construction—students build and refine their conceptual understanding; (iv) Interactivity—students compare solutions across multiple apps or AI tools, encouraging mathematical discussion; and (v) Linkage—Photomath reveals underlying steps that connect to previously learned mathematical concepts.

The questionnaire was distributed to alums and third-year aerospace engineering students at a private university in Yogyakarta, while classroom implementations (Cycles 1 and 2) involved first-year students. The questionnaire included a mix of scaled and open-ended questions to explore students' and alums' perceptions of realistic mathematics in academic and workplace settings. It covered self-assessment of mathematical ability, the need for skill improvement, types and frequency of math use, and experiences with digital tools like Photomath. Respondents were also asked about preferred learning activities and common challenges in understanding or applying math. The instructional focus for these cycles was on integral strategies in calculus, chosen as the core content for developing the Hypothetical Learning Trajectories (HLT), as seen in Table 1.

Table 1. The HLT

Activities	Conjecture
1. Students were asked to solve an integration problem using Photomath and observe the solving steps.	Students will follow the steps carefully and gain understanding from the detailed solution provided by the app.
2. Students discussed Photomath's solution with peers and identified steps they did not understand.	Students will collaboratively clarify confusing steps and deepen their understanding.
3. Students rewrote the solution in their own words and reasoning.	Students can reconstruct the solution and explain the logic behind each step.
4. Students were guided with lecturer questions to recall prior knowledge related to integral techniques	Students will recall formulas and methods from previous learning to connect with current problems.
5. Students created video explanations of a solved integration problem using their own words.	Students will demonstrate their understanding through verbal explanation and identify the reasoning behind their steps.
6. Students completed a reasoning-focused mid-test assessing their ability to explain problem-solving steps.	Students engaged in previous activities will reason more clearly and avoid rote answers.

Data from the questionnaire were analyzed qualitatively to identify what aerospace engineering students consider realistic mathematics during their studies and in their workplace. These insights informed the design of the HLT, which was then implemented and refined through two classroom cycles. The outcome of this research is a validated learning design that integrates RME principles and mobile mathematics applications to support conceptual reasoning in calculus. Although not yet formulated into a Local Instruction Theory (LIT), this learning design provides a foundational step toward it, offering a practical model for future implementation and theoretical development.

III. Results and Discussion

Questionnaire result

The alums perceive that their mathematics skills are average, but 60% still want to upgrade and develop their mathematics skills. Due to the necessity of their workplace, up to 70% need mathematics. Most of them need mathematics for analysing data and calculating some aerospace formulas. Meanwhile, the questionnaire results from the third-year students of Aerospace Engineering said that their mathematics skills are 75% average. Accordingly, just 50% of them want to increase their skills because they thought their level was enough to overcome mathematics in their last year of study. The fact that the application becomes realistic for many alums of aerospace engineering should be used in the learning activity. Many mathematics applications have spread out, and students must choose the most useful one. The designed HLT aims to reveal students' mathematics skills with the help of applications or AI. In brief, students can use applications to solve an integration problem. Later on, they have to understand the solving steps given by the application and rewrite and explain them in their way.

Cycle 1.

In the first cycle, students were introduced to integral problems. They were instructed to individually explore a variety of mathematics mobile applications such as Photomath, Symbolab, and ChatGPT to solve them. This cycle aimed to observe how students interact with different technologies and which applications support their understanding best. Each student was assigned a different app to ensure a range of user experiences. After using these tools, students were asked to reflect on the clarity, completeness, and usefulness of the solution steps provided.

Through class discussions and feedback, it became evident that many applications had limitations. For instance, some apps required payment to access complete solution steps, while others provided only brief or incomplete answers. Students noted frustration with these limitations, especially when following the logic behind each integration step.

Figure 1. Students use photomath

As shown in Figure 1, most students found Photomath to be the most accessible and user-friendly tool. It offered clear, step-by-step solutions without cost, which helped students follow and understand the process more effectively. Based on these findings, the Hypothetical Learning Trajectory (HLT) was revised for the second cycle to focus solely on using Photomath as the primary digital tool to support students' mathematical reasoning and discussion.

Cycle 2.

In the second cycle, the instructional activity was refined based on the findings from Cycle 1. Students were now directed to use a specific mobile application (Photomath) to solve integral problems, as illustrated in Figure 2. The decision to focus on this app was based on students' earlier feedback highlighting Photomath's clear, step-by-step solutions and free accessibility.

The activity began with students solving selected integral problems using Photomath. Following this, they were asked to engage in small-group discussions to compare and reflect on the problem-solving procedures displayed in the app. Each student was then tasked with rewriting the solution in their own words, emphasizing their understanding of the mathematical reasoning behind each step.

Students were also assigned a video project to deepen their engagement and encourage verbal articulation of their thought processes. Each student selected an integration problem in this task and recorded themselves explaining the solution, using Photomath as a reference. This project aimed to assess both their conceptual understanding and communication skills.

Three distinct patterns emerged from the students' video submissions:

1. **Reading only**: students read their written solutions without elaborating or providing further insight.
2. **Rewriting with explanation**: students rewrote the solutions while providing basic commentary.
3. **In-depth explanation**: Students explained the complete solution clearly and sometimes rewrote parts during the video to highlight key concepts or previously implicit steps.

To evaluate the impact of these activities, a mid-test was administered, focusing not on final answers but on **reasoning and justification of solving steps**. The results showed that most students could reason based on classroom discussions and peer interactions. However, a portion of students relied solely on prior knowledge, often resorting to recalculating rather than explaining a pattern consistent with

JURNAL GANTANG. May 2025; X(1): 45 – 52
p-ISSN. 2503-0671
e-ISSN. 2548-5547

inductive reasoning. As Elsayed & Almahri (2023) noted, such reasoning involves verification rather than creativity, offering little new conceptual insight.

This cycle helped reveal varying levels of mathematical reasoning among students and highlighted the effectiveness of combining RME principles with digital tools in fostering deeper understanding in an engineering context.

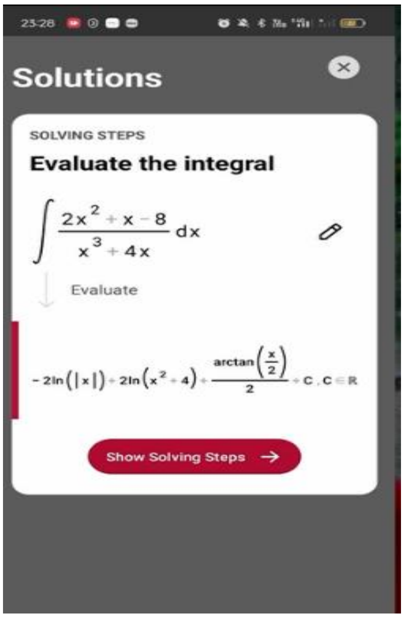

Figure 2. Photomath solving steps

Discussion

The interlinking between engineering problems and basic mathematics is still challenging to understand (Patil et al., 2022). Thinking about mathematics helps students succeed in real life (Elsayed & Almahri, 2023). Studies suggest giving simple and basic examples to build a bridge between engineering and mathematics (Kortemeyer & Biehler, 2022; Tum, 2024).

These instructional activities are designed to represent application mathematics with examples in the particular field of aerospace engineering. In addition, students are now addicted to technology like Symbolab, Photomath, and Chat GPT, which help solve mathematics problems. The free version of Chat GPT still does not support mathematical symbols, so it is very difficult for students to understand the solution. Meanwhile, the photomath provides more detailed steps, but some are still missing. These missing steps are a good way to facilitate students' reasoning skills. Since we could ask how does it happen? Reasoning teaches us to use discourses such as "if… then…" and "Because…" regarding drawing conclusions and making assumptions (Dhungana & Thapa, 2023).

Mathematics students use mainly two types of reasoning skills, namely imitative reasoning and creative reasoning, to solve mathematical tasks. The solving steps on photo math are purposefully used to increase and develop students' imitative and inductive reasoning so that they can generate creative reasoning when they solve the problem themselves.

IV. Conclusion

Providing students with the opportunity to articulate their mathematical thinking through peer discussion, written explanations, or multimedia presentations proved more meaningful than simply asking whether they understood the material. The integration of Photomath within instructional activities revealed how students approached integral problems, often demonstrating imitative and inductive reasoning patterns. While the application supported procedural understanding, students frequently used it to verify steps rather than construct new knowledge, highlighting the importance of guidance in transitioning from surface-level to deeper mathematical reasoning.

Grounded in realistic workplace contexts, the learning activities designed in this study facilitated a closer connection between formal mathematics and practical application in engineering. The outcomes point to a promising instructional approach that blends digital tools with RME principles to develop mathematical reasoning in relevant, contextual, and accessible ways. This design contributes to the ongoing refinement of teaching practices that support meaningful learning in higher education mathematics, particularly within engineering disciplines.

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