International Journal of Education, Culture, and Society

e-ISSN : 3024-8973
p-ISSN : 3024-8981

Index: Harvard, Boston, Sydney University, Dimensions, Lens, Scilit, Semantic, Google, etc

https://doi.org/10.58578/IJECS.v3i3.6123

The Potential of Android Learning Media Based on Visual Representation to Improve Students' Representation and Systems Thinking Skills: A Review from a Student Teacher's Perspective

Fatynia Ilmiyatni[1], Marina Setyarini[2], Dewi Lengkana[3]
University of Lampung, Bandar Lampung, Indonesia
m.setyarini@fkip.unila.ac.id

Article Info:

Submitted:	Revised:	Accepted:	Published:
Apr 22, 2025	May 18, 2025	May 30, 2025	Jun 5, 2025

Abstract

Despite growing recognition of the importance of representation and systems thinking skills in science education, limited research has explored the use of Android-based learning media grounded in visual representations to support these competencies. This study aims to characterize Android learning media designed with visual representations and examine perceptions of its effectiveness in enhancing students' representational and systems thinking skills. Employing an explanatory sequential mixed-methods design, the research involved 44 science teachers and 244 junior high school students across Lampung Province, Indonesia. Quantitative data were collected through structured questionnaires, followed by qualitative interviews to elaborate on the initial findings. Data analysis employed appropriate statistical and thematic techniques. The results indicate that both teachers and students hold favorable perceptions of visual representation-based Android learning media, recognizing its potential to support student understanding and cognitive development in science. The study concludes that such media are perceived as effective tools for improving students' abilities in scientific representation and systems

IJECS Journal is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License

thinking. Theoretically, the study contributes to the growing body of literature on educational technology and visual learning tools in science education. Practically, it encourages educators and curriculum developers to integrate these tools to address gaps in students' representational competence and implicit system thinking. Future research is recommended to examine the long-term impacts and effective integration strategies of visual representation-based digital media in diverse learning environments.

Keywords: Android Learning Media; Visual Representation; Representation Skills; Systems Thinking Skills; Science Education

INTRODUCTION

The 21st century's rapid proliferation of science and technology (S&T) has ushered in significant educational challenges (Alimiah et al., 2021; Wu et al., 2021). An important change is how we get information, with students and the general public increasingly dependent on mobile devices, especially Android smartphones (Ambarita et al., 2020; Mu, 2017; Sophia & Yensasnidar, 2019). This widespread shift has driven the growth of mobile learning (m-learning), which offers a fresh and exciting way to improve our teaching and learning. However, to truly make the most of m-learning, we need careful thought, real-world application, and teamwork among all those involved (Baydas & Yilmaz, 2018; Ningsih & Adesti, 2020; Pereira & Rodrigues, 2013).

Leveraging its adaptable nature for delivering educational content, Android-based mobile learning incorporates a range of visual tools, such as text, graphics, and interactive elements (Hakim et al., 2020; Saputra & Kuswanto, 2019). The ability to access it whenever and wherever empowers educators to broaden their teaching approaches (Putranta et al., 2021; Wirjawan et al., 2020), leading to a richer learning experience. Through the integration of interactive features and captivating visuals, Android m-learning shows great potential as a powerful educational resource for today's digitally connected students (Meliana, 2019; Tamhane et al., 2015), a trend that aligns with the increasing understanding of how vital visualisation is in both scientific advancement and science instruction (Tytler, 2021).

A fundamental aspect of the science and biology curriculum is the study of the interactions between living organisms and their environment. Comprehending these

relationships is vital for understanding ecological systems and their implications for environmental sustainability. However, students often find this topic complex, hindering their ability to achieve deep and applicable knowledge. Abstract scientific concepts become challenging to grasp without tangible context, and the transfer of learning heavily depends on how these concepts are represented (Braithwaite & Goldstone, 2015). Consequently, students often struggle to connect prior knowledge with new ideas, impacting their ability to construct meaningful understanding (Prabha, 2020; Treagust & Duit, 2008).

This topic's inherent complexity and abstract nature often necessitate a systems thinking approach, involving the application of knowledge, conceptual understanding, and exploring representations. Furthermore, the traditional classroom setting offers limited opportunities for direct and comprehensive observation of these interactions, which often require considering not just individual organisms but also the dynamics at the population level (Hokayem & Gotwals, 2016; Sophia & Yensasnidar, 2019). Interactive and technology-driven learning media, capable of providing more precise and engaging visual representations, can significantly aid students in navigating these complex concepts. Visual representations, such as graphs, animations, and simulations, can effectively simplify comprehending challenging and abstract ideas.

Visual representation is a crucial bridge, linking abstract concepts to more readily understandable concrete realities. Its integration has become indispensable in science, enabling learners to engage with intricate and often unobservable phenomena, thereby facilitating the acquisition of new knowledge (Afify, 2018; Evagorou et al., 2015; Tijsma et al., 2020). The effective use of representations in science education has been shown to enhance student learning and foster deeper understanding (Hill & Sharma, 2015). By presenting information through images, diagrams, or animations, visual representations assist students in building more transparent and more robust mental models of natural phenomena, facilitating better retention and the ability to connect related concepts. Consequently, it is paramount for educators to cultivate and develop students' representational competence in science education (Yunus et al., 2021).

However, research indicates that students' representation abilities remain underdeveloped (Lestari, 2018). This can be attributed to science learning activities that often prioritise rote memorisation over active engagement in scientific practices and applying concepts in novel situations (Prabha, 2020). Human cognitive processing struggles

with abstract and poorly represented information, underscoring the need for effective strategies to facilitate understanding of learned concepts. Visual representation learning, by fostering connections between pictorial and verbal information, can accommodate more information and ultimately enhance students' comprehension and thinking skills (Liu et al., 2020; Ma'ruf et al., 2019; Petersen et al., 2018; Toetenel & Rienties, 2016).

Comprehending the intricate relationships within ecosystems necessitates visual representation and robust thinking skills, with systems thinking particularly crucial. Systems thinking involves understanding a system's components' interconnectedness and mutual influence. This ability empowers students to grasp the interdependencies between concepts and processes, cause-and-effect relationships, and system elements' responsibilities (Boehnert, 2018; Petersen et al., 2018). However, traditional teaching often isolates concepts, hindering students' ability to forge these crucial connections and develop a holistic understanding of ecosystems. Despite its importance in facilitating the integration of knowledge, systems thinking skills are not always fully implemented in educational practices (Schuler et al., 2017).

Recognising the potential of technology to address these challenges, particularly through Android-based learning media, offers an opportunity to create more interactive and immersive learning experiences that can foster a deeper and more comprehensive understanding of ecosystems. Effective learning occurs when instruction aligns with learning objectives (Mu, 2017), highlighting the need for learning media designed for optimal effectiveness and efficiency (Liu et al., 2020; Sophia & Yensasnidar, 2019). Nevertheless, visual representation-based m-learning resources, especially in Indonesia, remain limited. Existing materials often lack engagement, detail, real-world relevance, and questions that promote higher-order thinking skills (Chen & Tsai, 2021; Utami & Subiantoro, 2021). The continued prevalence of teacher-centred approaches hinders the development of students' thinking skills (Mat & Mustakim, 2021).

To address these limitations and optimise students' thinking and representation abilities, this research explores the integration of learning through visual representation-based Android m-learning. Prior studies suggest that mobile learning can foster student-centred environments, thereby enhancing thinking skills (Chen & Tsai, 2021; Hokayem & Gotwals, 2016). Furthermore, learning media incorporating visual representations can effectively support the development of these skills by allowing students to interact with

models of complex systems directly (Chen & Tsai, 2021; Eilam, 2012; Green et al., 2022), potentially leading to improved and accelerated knowledge acquisition and application. Therefore, this research is essential to ascertain the perceptions of teachers and students regarding the development of Android learning media that utilizes visual representations for the topic of interaction of living things and their environment, specifically aiming to enhance students' representation abilities and systems thinking. The findings from this study can serve as a crucial framework for designing Android learning media, ensuring that the developed resources effectively improve students' representational capacities. Furthermore, these results will offer valuable insights into the preparedness of both teachers and students to effectively utilize Android learning media in the classroom.

METHODS

This study uses a mixed methods design adapted from Creswell. The strategy used is an explanatory sequential design combining qualitative and quantitative data collection (Creswell, and Guetterman, 2019). The respondents in this study consisted of 44 science teachers and 244 students. Quantitative data were collected through online questionnaires. The research design scheme can be seen in Figure 1.

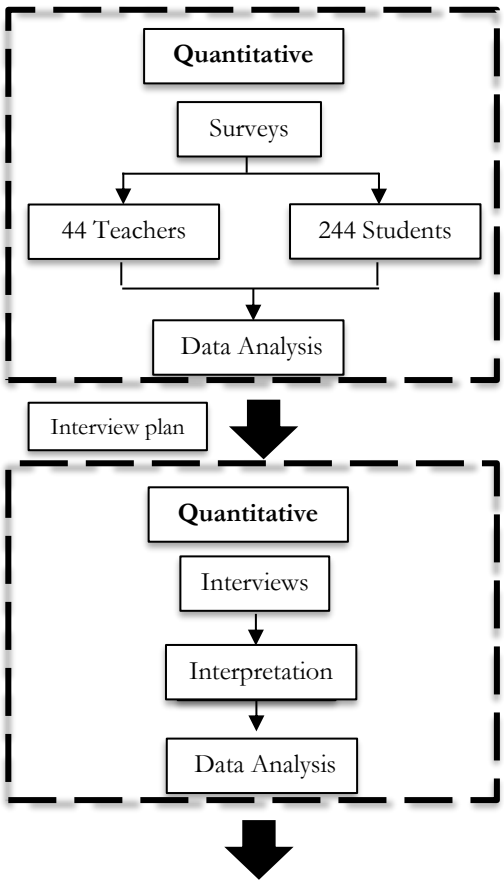

Figure 1. Research Design Scheme

The questionnaire addressed five aspects: mobile learning, Android learning media based on visual representations, the interaction between living things and their environment, systemic thinking skill and representation abilities. The Guttman scale was used in this research, where responses were selected based on the question's content as either "YES" or "No," corresponding to a score of "1" and "0," respectively (Sudjana, 2005). Following the questionnaire results analysis, semi-structured interviews were conducted with 8 teachers. The calculated percentage scores were then interpreted using qualitative descriptions. These interviews aimed to explore the reasons behind the instructional media used for learning and strategies to enhance students' systemic thinking and representational abilities. The instrument's validity was confirmed via product-moment correlation analysis, while its reliability was assessed using Cronbach's alpha coefficient at a 5% significance level. The validity of its instrument were analysed using SPSS version 25.0.

RESULTS

Perceptual data from teachers and students concerning the creation of Android-based learning media, designed with visual representations to foster improved representational abilities, was acquired through questionnaire completion. The results of the questionnaire filled out by 44 science teachers in Lampung Province are shown in Table 1.

Table 1. Percentage of Teacher Perception Questionnaire

No.	Question	Percentage (%)	
		Yes	No
1.	Educator's understanding of mobile learning	100	0
2.	The use of mobile learning in science education	63,64	36,36
3.	The Benefits of using mobile learning	81,82	18,18
4.	The need for learning media that can be accessed using mobile devices	97,48	2,23
5.	The weaknesses in the implementation of mobile learning	84.1	15,90
6	The use of learning media in the topic of the interaction of living things and their environment	97,98	2,23
7	The application of interaction pattern analysis in a given ecosystem through an image of the ecosystem	88,63	11,37

No.	Question	Percentage (%)	
		Yes	No
8	The determination of appropriate images or visuals in the topic of the interaction of living things and their environment	100	0
9	The use of visual representation in learning the topic of the interaction of living things and their environment	97,73	2,27
10	The use of feedback in the topic of the interaction of living things and their environment	84,1	15,90
11	The difficulties in learning the topic of Interaction of Living Things and their Environment	93,19	6,81

Table 1 provides a survey of 44 teachers indicates that mobile technology plays a significant role in science education, with 76.9% of educators using it. However, teachers struggle to teach the circulatory system, which impacts student comprehension effectively. They believe varied visual representations (pictures, graphs, tables) are crucial for student understanding and for students to explain concepts in diverse ways. Despite this, teachers currently don't train students in these representational abilities, which affects their conceptual understanding. Teachers are confident that mobile learning applications providing accessible, visually rich explanations would greatly aid students in learning abstract science concepts.

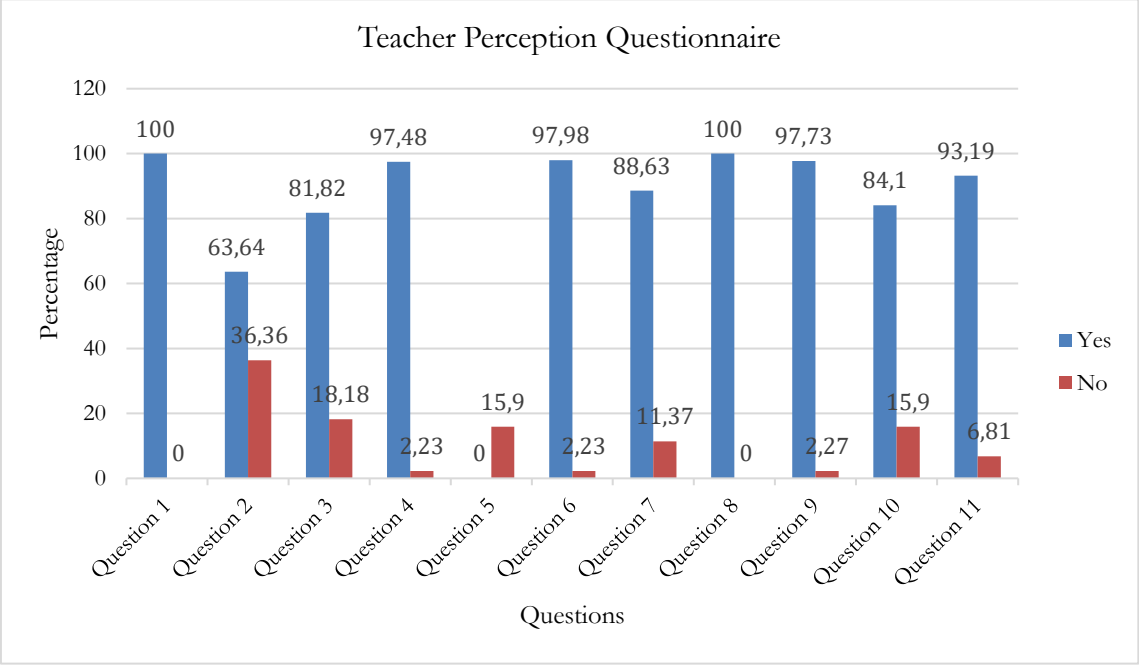

Figure 2. Percentage of Teacher Perception Questionnaire

Figure 2 provides a visual representation of the quantitative data gathered from science teachers regarding various aspects of their perception towards mobile learning and visual representations in science education. This bar chart distinctly illustrates the percentage of teachers who responded "Yes" or "No" to each of the eleven questions asked in the questionnaire. For instance, it shows a 100% agreement on "Educator's understanding of mobile learning" (Question 1) and "The determination of appropriate images or visuals in the topic of the interaction of living things and their environment" (Question 8). Conversely, it highlights areas like "The use of mobile learning in science education" (Question 2) where only 63.64% of teachers indicated "Yes," alongside 36.36% saying "No," and "The difficulties in learning the topic of Interaction of Living Things and their Environment" (Question 11) with a high 93.19% "Yes" response. This visual format allows for a quick and clear comparison of teacher perceptions across different queried aspects.

The results of the questionnaire filled out by 244 junior high school students in Lampung Province are shown in Table 2.

Table 2. Percentage of Student' Perception Questionnaire

No.	Question	Percentage (%)	
		Yes	No
1.	The use of handphone in learning	100	0
2.	The Use of learning media in the topic of the interaction of living things and their environment	63,64	36,36
3.	The Feeling of pleasure when learning using visual representations (pictures, graphs, etc.)	81,82	18,18
4.	The Feeling of ease in understanding science concepts when learning using visual representations	97,48	2,23
5.	The difficulty in studying the interaction system of living things and their environment	84.1	15,90
6	The Need for Android learning media to study the interaction of living things and their environment	97,98	2,23

Table 2 provides a survey of 244 students revealed that they generally experience satisfaction when learning science through their mobile phones (96% agreed). Furthermore, a strong majority (96%) found enjoyment in having concepts explained using visual representations, such as pictures. This positive disposition significantly contributes to

students' clear comprehension of concepts, with 100% of students reporting ease in understanding science concepts when visual representations are used. However, the text specifically mentions that an insufficient use of visual representations when teaching the interaction of living things and their environment can lead to student difficulties in understanding the concept. This aligns with the table's finding that 100% of students acknowledged difficulty in studying the interaction system of living things and their environment (a concept that likely benefits from visual aids). Students strongly believe that easily accessible learning resources, particularly those that offer diverse and appropriate visual representations (as highlighted by the 96,49% agreement on the need for Android learning media for interaction of living things and their environment and the 100% agreement on the ease of understanding with visuals), would greatly assist their learning, especially for challenging topics like the interaction of living things and their environment.

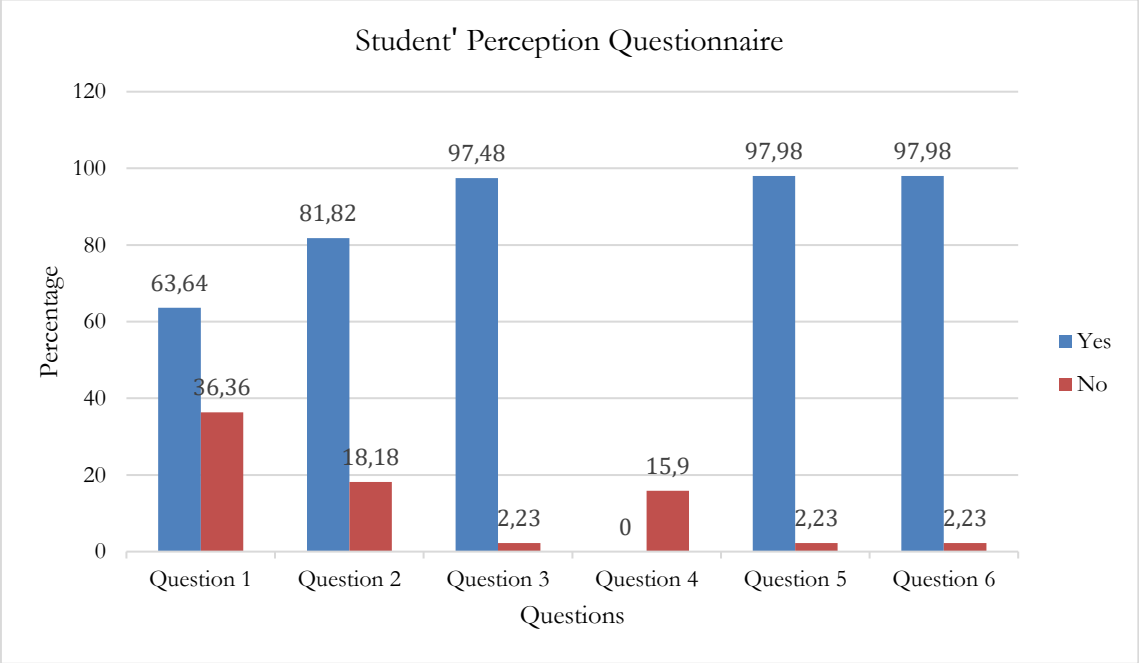

Figure 3. Percentage of Student' Perception Questionnaire

Figure 3 shown visual representation of the quantitative data gathered from junior high school students regarding various aspects of their perception towards mobile learning and visual representations in science education. The Student's Perception Questionnaire graph reveals predominantly positive student perceptions across six questions, with very high "Yes" percentages (over 97%) for Questions 3, 5, and 6, and a majority "Yes" for Question 2 (81.82%) and Question 1 (63.64%). However, Question 4 presents an anomaly

with 0% "Yes" and only 15.9% "No," suggesting incomplete data or a need for clarification. Generally, students hold positive perceptions, but this specific data point warrants further examination.

DISCUSSION

The findings of this study suggest that the integration of Android learning media has the potential to significantly enhance students' system thinking and representative skills. This implies that by providing students with interactive, mobile-based learning experiences, they can develop a more comprehensive understanding of complex systems and improve their ability to effectively model, visualize, and communicate information. Interviews with science teachers reveal a growing adoption and familiarity with mobile learning. Many teachers now integrate smartphones into their instruction, primarily for accessing online information. They recognise mobile learning's key benefit: providing students with flexible, anytime, anywhere access to educational content. As one teacher articulated that *"Mobile learning is technology-assisted learning that can be accessed and studied anywhere. Beyond that, it makes learning more interactive and fun, and allows students to manage their own study time more flexibly"*. Mobile learning stands out as a current and engaging educational medium, operating through mobile technology like smartphones and tablets. Its effectiveness stems from providing constant access to learning materials and presenting content through appealing, interactive visualisations (Bernacki et al., 2020; Hakim et al., 2020). The combination of interactive functionalities and captivating visual elements within Android-based mobile learning (m-learning) positions it as a powerful learning tool for contemporary students (Meliana, 2019; Tamhane et al., 2015). This makes it particularly valuable in environments where traditional methods may fall short, allowing for greater student engagement, self-paced learning, and the cultivation of critical thinking skills through immersive digital experiences.

Electronic devices like cellphones are now widely utilized in education, with teachers employing them for various purposes such as facilitating student internet research, supporting discussions, and conducting formative assessments like quizzes and live worksheets. Teachers believe that *"Learning using cellphones will make students feel that they are not studying so that the material being studied will be easy to understand, besides that, features that can be accessed via cellphones which are already sophisticated will attract students' attention more"*. This aligns

with the idea that students find technologies useful when they enhance productivity, and their perceived ease of use correlates positively with their attitudes and intentions for continued adoption (Camilleri & Camilleri, 2023). Studies consistently demonstrate that positive emotions, such as joy, lead to favorable learning outcomes, encompassing increased enthusiasm, a willingness to tackle challenges, improved collaboration, excitement, and overall academic achievement (Hernik & Jaworska, 2018; Seemiller et al., 2021).

When using smartphones for learning, teachers must also consider potential risks, such as student dependence and challenges in managing device access and usage. As one teacher noted, *"We must also care and understand that the use of smartphones in learning also has risks that need to be considered, for example, the risk of dependence, challenges in managing access and use of smartphones"*. To address this, providing instructional support to monitor students' learning is crucial, and teachers can offer this support through mobile learning applications (Gunanto et al., 2019). Ultimately, integrating m-learning into the teaching process promises to be a more natural and effective learning method for current generations. As a result, more engaged and motivated students, increased information retention, and, ultimately, enhanced academic success may be achieved (Criollo-C et al., 2021). Mobile learning, characterised by its convenience, ubiquity, flexibility, and increasing capabilities of handheld devices like smartphones, has significantly piqued educators' interest as a tool to enhance teaching methods (Kearney et al., 2015). Technology has broadened educational horizons, reshaping the dynamics between teachers, students, and learning materials (Sulisworo & Toifur, 2016).

The effectiveness of a mobile learning application is indicated by its contribution to achieving learning objectives and student success. Representational abilities, which involve introducing students to various visual elements, can be developed during the learning process. However, some teachers are unaware of the importance of representational ability, thus neglecting it. As one teacher admitted, *"I just heard it, maybe it's important for students"*. Even teachers who understand its significance often don't prioritize it, with one stating, *"Of course, the ability to represent is very important for students to have because with this ability students will more easily understand concepts, remember information obtained in learning, but I don't pay much attention to it"*. The human mind struggles with abstract or poorly visualized concepts, emphasizing the need for effective learning strategies. Visual representations aid cognitive processing by linking images and words, thereby improving information retention, understanding, and

cognitive abilities (Liu et al., 2020; Ma'ruf et al., 2019; Petersen et al., 2018; Toetenel & Rienties, 2016). This is supported by the fact that meaningful visual information is selected by working memory and stored in long-term memory (Setyarini et al., 2017).

Mobile learning applications that incorporate diverse visual representations can cultivate students' representational abilities. Teachers believe that visuals, like pictures, clarify concepts and help develop these skills. As one teacher stated, *"By providing direct experience, providing teaching materials accompanied by good pictures, and holding discussions with groups can train students to represent concepts"*. However, teachers haven't measured students' representational abilities, so their development remains unknown, with one teacher admitting, *"I have never measured students' representational abilities"*. Visual elements such as pictures, graphs, tables, and diagrams aid conceptual understanding by effectively summarizing information (Evagorou et al., 2015). Both teachers and students believe that accessible learning media featuring varied, appropriate visual representations, coupled with opportunities for student practice and teacher monitoring, can enhance students' representational abilities.

From a systems thinking perspective, the development of student representational abilities is a crucial output of the learning system, directly impacting conceptual understanding. While introducing students to various visual elements serves as a vital input, the current pedagogical system exhibits a significant bottleneck: low teacher awareness and prioritization regarding these abilities. This systemic deficiency in training directly impacts student learning outcomes, as the human cognitive system struggles with abstract or poorly visualized concepts. Systems thinking can be effectively taught by exploring the interconnections among elements in real-life contexts. Thinking in systems can help students understand the interdependence between concepts and processes, the resulting impacts, and the responsibilities of elements within a system, making it easier to grasp (Boehnert, 2018; Petersen et al., 2018). However, one teacher noted that, *"Students have limitations in their ability to think systemically, particularly in identifying system components and understanding their functions, as well as explaining causal relationships or interdependencies between components. Students only acknowledge differences without being able to explain why or how these differing roles form a system"*.

Students' initial systems thinking ability remains low due to a lack of specific training in this area during learning. One teacher reported that, *"Students often struggle to apply*

this systemic thinking, especially when faced with science problems that require a deep understanding of how various components interact and influence each other within a system. They tend to view parts in isolation rather than as an integrated whole". They struggle to integrate existing representations, hindering the development of their systemic thinking. Systems thinking enables a holistic view of problems, akin to seeing the entire forest instead of individual trees. This approach is vital for addressing complex, interconnected real-world issues, particularly in sciences like biology. By understanding these interconnections, we can generate more creative, "out-of-the-box" solutions. This skill is also invaluable for managing daily complexities, ultimately leading to better problem-solving and societal improvement (Lavi & Dori, 2019). Both teachers and students agree that accessible learning media, especially those with diverse and appropriate visual representations, combined with opportunities for student practice and teacher monitoring, can significantly improve students' systemic thinking abilities. This approach helps students to better grasp complex relationships and interdependencies within systems.

Therefore, this research is essential to ascertain the perceptions of teachers and students regarding the development of Android learning media that utilizes visual representations for the topic of interaction of living things and their environment, specifically aiming to enhance students' representation abilities and systems thinking. The findings from this study can serve as a crucial framework for designing Android learning media, ensuring that the developed resources effectively improve students' representational capacities. Furthermore, these results will offer valuable insights into the preparedness of both teachers and students to effectively utilize Android learning media in the classroom.

Despite the promising findings regarding Android learning media's potential to enhance system thinking and representative skills, this study acknowledges several limitations. The short duration of the study and its sole reliance on survey data restrict the generalizability and the assessment of long-term impacts. To address these limitations, future research should implement a more comprehensive approach. This includes expanding the instrument used to enhance the broader applicability of the findings, incorporating control groups to isolate the true effects of the Android learning media, and employing longitudinal designs to assess the lasting impact and sustained benefits of this educational integration on students' cognitive abilities.

CONCLUSION

This study concludes that Android Learning Media Based on Visual Representation is perceived positively by teachers and students as a valuable tool to improve Students' Representation and System Thinking Skills, particularly due to its ability to clarify concepts and offer accessible, engaging learning experiences. Teachers and students share a favorable view regarding the integration of Android learning media, which utilizes visual representations, in science education to enhance students' representational and, by extension, their systems thinking abilities.

The integration media helps students develop their system thinking by providing structured guidance, enabling them to understand interconnected concepts. This approach also enhances their representative skills, as they learn to model and interpret information effectively within the digital environment.

The findings suggest that visually-rich Android learning media can enable students to not only grasp scientific concepts but also cultivate strong representational skills, a vital component for developing 21st-century competencies like problem-solving. Furthermore, teachers themselves see a critical need for these learning media in science instruction to actively train and develop students' representational capabilities, which are foundational for a holistic systems thinking approach to complex scientific problems.

REFERENCES

Afify, M. K. (2018). *Journal of Technology and Science Education E-Learning Content Design Standards Based On Interactive Digital Concepts Maps In The Light Of Meaningful And*. *8*(1), 5–16.

Alimiah, U. S., Mariana, A., & Linuwih, S. (2021). The Use of Android Based M-Learning toward Understanding Concept on Motion System Subject. *Journal of Innovative Science Education*, *2021*(37). http://journal.unnes.ac.id/sju/index.php/jise

Ambarita, D., Nainggolan, E., Tamba, R., & Perangin-Angin, L. (2020). *The Development of Learning Media Based Android on Students Development Subject*. https://doi.org/10.4108/eai.17-12-2019.2296041

Baydas, O., & Yilmaz, R. M. (2018). Pre-service teachers' intention to adopt mobile learning: A motivational model. *British Journal of Educational Technology*, *49*(1), 137–152. https://doi.org/10.1111/bjet.12521

Bernacki, M. L., Greene, J. A., & Crompton, H. (2020). Mobile technology, learning, and achievement: Advances in understanding and measuring the role of mobile technology in education. *Contemporary Educational Psychology*, *60*(November 2019). https://doi.org/10.1016/j.cedpsych.2019.101827

Boehnert, J. (2018). The visual representation of complexity: Sixteen key characteristics of complex systems. *Relating Systems Thinking and Design 7*, 347–363. http://openresearch.ocadu.ca/id/eprint/2737/

Braithwaite, D. W., & Goldstone, R. L. (2015). Effects of Variation and Prior Knowledge on Abstract Concept Learning. *Cognition and Instruction*, *33*(3), 226–256. https://doi.org/10.1080/07370008.2015.1067215

Camilleri, M. A., & Camilleri, A. C. (2023). Learning from anywhere, anytime: Utilitarian motivations and facilitating conditions for mobile learning. In *Technology, Knowledge and Learning* (Vol. 28, Issue 4). https://doi.org/10.1007/s10758-022-09608-8

Chen, C. H., & Tsai, C. C. (2021). In-service teachers' conceptions of mobile technology-integrated instruction: Tendency towards student-centered learning. *Computers and Education*, *170*, 104224. https://doi.org/10.1016/j.compedu.2021.104224

Creswell, J.W. and Guetterman, T. C. (2019). *Educational Research: Planning, Conducting, and Evaluating Qualitative and Quantitative Research*. Pearson.

Criollo-C, S., Guerrero-Arias, A., Jaramillo-Alcázar, Á., & Luján-Mora, S. (2021). Mobile learning technologies for education: Benefits and pending issues. *Applied Sciences (Switzerland)*, *11*(9). https://doi.org/10.3390/app11094111

Eilam, B. (2012). System thinking and feeding relations: Learning with a live ecosystem model. *Instructional Science*, *40*(2), 213–239. https://doi.org/10.1007/s11251-011-9175-4

Evagorou, M., Erduran, S., & Mäntylä, T. (2015). The role of visual representations in scientific practices: from conceptual understanding and knowledge generation to 'seeing' how science works. *International Journal of STEM Education*, *2*(1), 1–13. https://doi.org/10.1186/s40594-015-0024-x

Green, C., Molloy, O., & Duggan, J. (2022). An empirical study of the impact of systems thinking and simulation on sustainability education. *Sustainability (Switzerland)*, *14*(1), 1–34. https://doi.org/10.3390/su14010394

Gunanto, P. E., Sujarwanta, A., & Widowati, H. (2019). Pengembangan Media Pembelajaran Mobile Learning Berbasis Android pada Materi Invertebrata untuk siswa Kelas X SMA. *Jurnal Lentera Pendidikan Pusat Penelitian LPPM UM Metro*, *4*(2), 72–77. https://ojs.ummetro.ac.id/index.php/lentera/article/view/1087%0Ahttp://files/158/Gunanto et al.

Hakim, D. L., Herman, T., & Kartasasmita, B. G. (2020). The use of mobile learning at SMP Negeri 3 Karawang Barat in improving students' mathematical representation ability. *Journal of Physics: Conference Series*, *1663*(1). https://doi.org/10.1088/1742-6596/1663/1/012038

Hernik, J., & Jaworska, E. (2018). the Effect of Enjoyment on Learning. *INTED2018 Proceedings*, *1*(May), 508–514. https://doi.org/10.21125/inted.2018.1087

Hill, M., & Sharma, M. D. (2015). Students' representational fluency at university: A cross-sectional measure of how multiple representations are used by physics students Using the representational fluency survey. *Eurasia Journal of Mathematics, Science and Technology Education*, *11*(6), 1633–1655. https://doi.org/10.12973/eurasia.2015.1427a

Hokayem, H., & Gotwals, A. W. (2016). Early elementary students' understanding of

complex ecosystems: A learning progression approach. *Journal of Research in Science Teaching*, *53*(10), 1524–1545. https://doi.org/10.1002/tea.21336

Kearney, M., Burden, K., & Rai, T. (2015). Investigating teachers' adoption of signature mobile pedagogies. *Computers and Education*, *80*(February 2019), 48–57. https://doi.org/10.1016/j.compedu.2014.08.009

Lavi, R., & Dori, Y. J. (2019). Systems thinking of pre- and in-service science and engineering teachers. *International Journal of Science Education*, *41*(2), 248–279. https://doi.org/10.1080/09500693.2018.1548788

Lestari, S. (2018). Peran Teknologi dalam Pendidikan di Era Globalisasi. *Edureligia; Jurnal Pendidikan Agama Islam*, *2*(2), 94–100. https://doi.org/10.33650/edureligia.v2i2.459

Liu, Z. J., Levina, V., & Frolova, Y. (2020). Information visualization in the educational process: Current trends. *International Journal of Emerging Technologies in Learning*, *15*(13), 49–62. https://doi.org/10.3991/ijet.v15i13.14671

Ma'ruf, M., Setiawan, A., & Suhandi, A. (2019). Identification of Android-based interactive multimedia needs for basic physics content. *AIP Conference Proceedings*, *2194*(December). https://doi.org/10.1063/1.5139792

Mat, H., & Mustakim, S. S. (2021). The Effectiveness of Virtual Learning to Enhance Higher Order Thinking Skills in Year 5 Students. *International Journal of Academic Research in Progressive Education and Development*, *10*(2), 577–584. https://doi.org/10.6007/ijarped/v10-i2/10140

Meliana, D. (2019). *Developing an android-based biology learning module utilizing local ecosystem materials to improve thinking skills of senior high school students*. 34–41. http://seminar.uny.ac.id/sseis/sites/seminar.uny.ac.id.sseis/files/2019/B-6_T_Aminatun.pdf

Mu, L. '. (2017). Learning Media Of Applications Design Based Android Mobile Smartphone. *International Journal of Applied Engineering Research*, *12*(17), 6576–6585. http://www.ripublication.com

Ningsih, S., & Adesti, A. (2020). *Android-Based Mobile Learning: Its Effect on Students' Learning Achievement*. *422*(Icope 2019), 100–103. https://doi.org/10.2991/assehr.k.200323.099

Pereira, O. R. E., & Rodrigues, J. J. P. C. (2013). Survey and analysis of current mobile learning applications and technologies. *ACM Computing Surveys*, *46*(2), 1–35. https://doi.org/10.1145/2543581.2543594

Petersen, J. E., Frantz, C. M., Tincknell, E., & Canning, C. (2018). An Animated Visual Representation of Real-Time Resource Flows Through a Community Enhances Systems Thinking. *Systems Research and Behavioral Science*, *35*(6), 718–737. https://doi.org/10.1002/sres.2514

Prabha, S. (2020). Students' Views on Difficulties in Conceptual Understanding of Science at Secondary Stage. *The Eurasia Proceedings of Educational & Social Sciences (EPESS)*, *16*, 1–10. www.isres.org

Putranta, H., Supahar, Setiyatna, H., Choiriyah, S., Dwandaru, W. S. B., Widodo, & Warsono. (2021). The Effect of Smartphone Usage Intensity on High School Students' Higher Order Thinking Skills in Physics Learning. *Journal of Turkish Science Education*, *18*(3), 421–438. https://doi.org/10.36681/tused.2021.82

Saputra, M. R. D., & Kuswanto, H. (2019). The effectiveness of Physics Mobile Learning

(PML) with HomboBatu theme to improve the ability of diagram representation and critical thinking of senior high school students. *International Journal of Instruction*, *12*(2), 471–490. https://doi.org/10.29333/iji.2019.12230a

Seemiller, C., Grace, M., Campagnolo, P. D. B., Alves, I. M. D. R., & De Borba, G. S. (2021). What makes learning enjoyable? Perspectives of today's college students in the U.S. and Brazil. *Journal of Pedagogical Research*, *5*(1), 1–17. https://doi.org/10.33902/JPR.2020065267

Setyarini, M., Liliasari, Kadarohman, A., & Martoprawiro, M. A. (2017). the Effectiveness of Stereochemistry Based on 3D Visualization. *Cakrawala Pendidikan*, *1*(XXXVI), 91–101.

Sophia, A., & Yensasnidar. (2019). Android-Based Interactive Learning Multimedia Validity in Genetic Substance and Synthesis Protein for Students of Medical Laboratory Technology (TLM). *International Journal of Progressive Sciences and Technologies*, 123–126.

Sudjana. (2005). *Metode Statistika*. Tarsito.

Sulisworo, D., & Toifur, M. (2016). The role of mobile learning on the learning environment shifting at high school in Indonesia. *International Journal of Mobile Learning and Organisation*, *10*(3), 159–170. https://doi.org/10.1504/IJMLO.2016.077864

Tamhane, K., Khan, W. T., Tribhuwan, S. R., Burke, A. P., & Take, S. B. (2015). Mobile Learning Application. *International Journal of Scientific and Research Publications*, *5*(1), 22503153.

Tijsma, G., Hilverda, F., Scheffelaar, A., Alders, S., Schoonmade, L., Blignaut, N., & Zweekhorst, M. (2020). Becoming productive 21st century citizens: A systematic review uncovering design principles for integrating community service learning into higher education courses. *Educational Research*, *62*(4), 390–413. https://doi.org/10.1080/00131881.2020.1836987

Toetenel, L., & Rienties, B. (2016). Learning Design – creative design to visualise learning activities. *Open Learning*, *31*(3), 233–244. https://doi.org/10.1080/02680513.2016.1213626

Treagust, D. F., & Duit, R. (2008). Conceptual change: a discussion of theoretical, methodological and practical challenges for science education. *Cultural Studies of Science Education*, *3*(2), 297–328. https://doi.org/10.1007/s11422-008-9090-4

Tytler, R. (2021). The role of visualisation in science: a response to "Science teachers' use of visual representations". *Studies in Science Education*, *57*(1), 129–139. https://doi.org/10.1080/03057267.2020.1766826

Utami, R. K., & Subiantoro, A. W. (2021). Visual Representations Analysis of Senior High School Biology Textbooks About Plants' Structure and Function. *Proceedings of the 7th International Conference on Research, Implementation, and Education of Mathematics and Sciences (ICRIEMS 2020)*, *528*(Icriems 2020), 123–128. https://doi.org/10.2991/assehr.k.210305.019

Wirjawan, J. V.D., Pratama, D., Pratidhina, E., Wijaya, A., Untung, B., & Herwinarso. (2020). Development of smartphone app as media to learn impulse-momentum topics for high school students. *International Journal of Instruction*, *13*(3), 17–30. https://doi.org/10.29333/iji.2020.1332a

Wu, W., Bakirova, G., & Trifonov, I. (2021). A shift towards visualization in eLearning.

International Journal of Web-Based Learning and Teaching Technologies, *16*(6), 1–12. https://doi.org/10.4018/IJWLTT.20211101.oa11

Yunus, S. R., Tawil, M., Muhiddin, N. H., Muhiddin, S. M. A., & Alim, M. H. (2021). Describing Representation Ability of Prospective Science Teacher Based on Learning Style. *Journal of Physics: Conference Series*, *1899*(1). https://doi.org/10.1088/1742-6596/1899/1/012141