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Chapter 1 - Facilitating Students' Understanding of Sustainable Development through Game Based Learning: A Systematic Literature Review

Novita Resti, Widi Purwianingsih, Kusnadi Kusnadi

Chapter Highlights

- Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
- Sustainable development should be introduced to young people as early as possible so that they have the knowledge and skills related to sustainable development to ensure that the environment and social well-being are sustainable for both current and future generations.
- Currently, there is a growing body of research on the use of game-based learning in teaching sustainable development. This article presents a literature review on the use of game based learning in facilitating students' understanding of sustainable development.
- In this study we systematically reviewed 20 scopus-indexed empirical research articles on game-based learning published from 2019 to 2023.
- The results of the review show that game based learning is feasible to be used in learning sustainable development because it can create active and interactive learning, able to demonstrate and teach sustainability issues, improve concept understanding in students, foster students' empathy towards society and the environment, increase students' motivation and interest in learning and positively affect their environmental awareness.

Introduction

The United Nations (UN) established the Sustainable Development Goals (SDGs) as a set of objectives to help all member states attain sustainable development. On September 25, 2015, in New York, the United States, the UN General Assembly adopted the Sustainable Development Goals (SDGs), which had been adopted by 190 nations. This global development agenda is valid from 2015 to 2030. According to Chen & Ho (2022), Development that satisfies current demands without jeopardizing the capacity of future generations to satisfy their own needs is known as sustainable development. This definition is the most cited in the world and also adopted by governments. The SDGs have 17 contents that cover the 3 elements of society, economy, and environment and emphasise coordination and progression among the three and avoid advancing one to the detriment of the other. According to Veronica & Calvano (2020), sustainability is a way of life that enables individuals to think and strive toward a better society for ourselves and others, both here on Earth and in the future, rather than merely a new subject to be taught in schools.

Sustainable development should be introduced to future generations as early as possible. According to Crohn & Birnbaum (2010), this is because fostering a harmonious relationship with nature needs to be done in the early developmental phase of children to ensure a longer lasting impact. In addition, the current generation is the generation that will face the environmental crisis (Lubchenco, 1998) so teaching sustainable development to them is an urgency. According to Tsai et al. (2021), the main purpose of teaching sustainable development is to provide students with knowledge and skills related to sustainable development to ensure that the environment and social welfare last for both current and future generations. In recent years, researchers have recognised the challenge of transforming traditional education models into forms that are more developmentally appropriate for adolescents and young people.

Boncu et al. (2022) state that the reception of information by the younger generation will be optimal when it matches their interests and information processing styles. Considering that the current generation is a generation that grew up with technology, there is a need for a method that can integrate technology in the learning process related to sustainable development so that it can attract students' interest. Although not all contexts are suitable for game design, formal and informal education environments are certainly susceptible to the use

of games in the process.

Nowadays, many educators are using game-based learning in learning. Game-based learning is a teaching strategy that combines multiple scientific subjects into a single lesson, makes learning easier by connecting new material to prior knowledge and life experiences, and promotes responsibility and active engagement. (Cordova & Lepper, 1996; Foster in Koenigstein, et al., 2020). According to Tan & Asna (2023), games today are not only used for entertainment but have been applied to non-entertainment functions such as in education and work. In practice, game-based learning not only pursues educational goals, such as improving health and physical well-being, but can also be used to promote sustainability and encourage pro-environmental behaviour (Stanitsas et al., 2019). Veronica & Calvano (2020) explain that games have been used to change behaviours and attitudes, improve learning outcomes and motivation in the fields of health, public policy, education, training, environmental behaviour and ocean literacy. Games have been used to link the scientific and social aspects of environmental problems (Bazan, 1976; Swinerton, 1972) and are a promising tool for teaching complex system interactions, to address modern global sustainability challenges (Uribe & Cobos, 2014). Given their favorable prospects for application in both formal and informal education environments, as well as their playfulness in appealing to today's kids, games and apps have a better potential to provide more immersive and enduring experiences than previous environmental education methods (Leeming et al., 2010).

Game-based learning utilises motivational effects that can capture students' attention. Integrating games into the classroom learning process is challenging as the game design and content must fit the curriculum, both in terms of relevance and efficiency. In addition, the games must also be in line with teachers‘ and students’ understanding of games as an activity in learning. Several studies have proven that the application of games in teaching can effectively increase children's learning motivation, thereby achieving teaching objectives and triggering a higher level of understanding of learning content. In addition, play can increase freedom, behavioural flexibility, and teach students the skills needed to live their lives. Play is fantastical and challenging, increasing curiosity and boosting motivation to participate. Sharp (in Parrondo et al., 2021) stated that knowledge gained from play is considered more effective because it is gained through practical learning.

Game-based learning according to Arboleya-García & Miralles (2022) allows students to be active participants, not passive observers, as they learn through participating in game activities i.e. problem solving, decision making, and reacting to the results of these activities. Games can activate the brain's reward system, stimulate retention and engage players towards cognition more effectively than traditional educational methods. Based on the above background, the researcher examined the potential of game-based learning in facilitating students' understanding of sustainable development.

The purpose of this study is to provide an overview of the various uses of game-based learning in sustainable development learning and explore their potential as an educational tool. In addition to examining research gaps that should be filled in future studies, this article aims to offer useful information about the intended results, effectiveness, and limitations of current methodologies.

Method

We searched the Scopus database for the search terms ‘game based learning’ and ‘sustainable development’. The search was conducted based on article abstracts, titles, and keywords. We used the following criteria: (a) articles discussing game-based learning for sustainable development; (b) research on all levels of education (elementary, middle, high school, university); (c) published in English (d) articles published between 2019-2023. For irrelevant studies such as games that are not related to sustainable development, are not intended for students and publications at congresses, seminars, conferences, degree projects, or doctoral theses are not used.

Results

Analysis of Scientific Production

We have observed 20 studies that fit the predefined criteria. Table 1 provides information on the geographical distribution of the sample. The studies were conducted in 23 countries spread across Europe, Asia, America and Australia. Most of the studies were from the European continent (N=16) with Spain (N=4) and Taiwan (N=4) as the countries with the most research on this topic, followed by Germany (N=3).

Table 1. Geographical Distribution of the Study Sample

Country	Number
Germany	3
Sweden	1
Poland	1
Italy	2
Taiwan	4
Spain	4
Portugal	1
England	2
Norway	1
USA	1
Thailand	1
Austria	1
Australia	1
Total	23

In the educational context in which this research was developed, three categories were presented (primary school, secondary school and university). Of the 20 selected articles, 21% of the research was conducted in primary schools, 54% in secondary schools and 25% in universities. In Table 2 there is an explanation of the name of the game that has been developed by the researchers, the type of game, the year of publication of the article, the topic of sustainable development discussed in the game, the target and the results obtained.

Table 2. Application of Game-Based Learning in Sustainable Development Learning

Name of Game	Types of Game	Year	Topic	Target	Result
Water Ark	Board game	2019	Water Resource Adaptation	A total of 21 students, 9 of whom were male, were included (18 to 20 years old)	The orientation of participants' strategies gradually changed from personal interests and benefits to altruistic strategies

					based on community social benefits. After playing Water Ark, participants of COSK, RWRE, VPB, and EaNT were found to have significantly improved.
M.O.S. (Marine, Ocean, Sea)	Board game	2019	Ocean	Senior high school student	The board game teaching method has better results than the traditional expository teaching method in terms of learning motivation, learning interest, and marine science learning achievement.
Eco	Simulation game	2019	Ecosystem	Two Norwegian high schools and three Norwegian University classes as well as four Facebook Group classes affiliated with environmental and gaming subjects	Eco is a viable tool to promote several aspects of ecosystem-related environmental awareness.
Green Machine	Card game	2019	Recycling plant	19 UK graduate students and 29	Green Machine is an innovative resource

				US second-year undergraduate students	that is fun to play with and engages students in learning the recycling process through systems thinking.
-	Web based	2019	Energy conservation	Students in primary schools of Bangkok Metropolitan Administration from 50 districts	This game resulted in the highest environmental awareness among primary school students.
CO_2peration	Digital games	2019	Climate change	First year of secondary school (12–13 years)	Climate literacy can be improved in this age group through digital games.
Ocean Limited	Role-playing game	2020	Ocean	Senior high school student	Real-world ocean sustainability challenges can be illustrated and taught through the game, which can also help groups learn how to solve problems involving socio-ecological conflicts and trade-offs in ocean use.
Climate Adaptation Game	Web-based	2020	Climate change	Students in Swedish high school (15 and 19 years old)	Players can reflect on the difficulties in making decisions about climate adaptation through games, but they can also highlight difficulties in making

					decisions about climate adaptation, such as the complexity of individual measurements and their inability to be linked to the inherent variability of extreme climate events.
SeAdventure	Serious game	2020	Ocean	46 pupils of two classes of the 4th grade of the 14 Didactic Circle ‘‘Re David’’ Primary School	Assessments of learning efficacy verify that children can, in fact, learn the material through the use of modern technologies in general and serious games in particular.
Biofuels and Bioenergy Game	Board Game	2020	Biofuels and alternative energies	Chemical Engineering student at the University of Granada	Increase student interaction and motivation. In addition, the game dynamics improved student learning, which was evaluated through student scores on the final exam.
The Island	Simulation game	2020	The economic, environmental (climate, soil) and social (energy infrastructure, housing,	First-year group of the natural sciences class	Universities should promote these types of workshops and SGs as they can contribute to the achievement of the SDGs.

			transport, jobs, etc.)		
E Eco JSity	Android-based mobile devices and as a web app	2021	Environmental literacy	The students of two Polish educational institutions	An effective way to integrate sustainable development concepts into the instruction of unrelated technical skills was through game-based learning.
Be Blessed Taiwan	Board game	2021	Sustainable development f four aspects-social development, economic growth, environmental protection, and animal survival	Senior high school student	Students' test scores improved significantly after playing the game with a medium effect size; specifically, a large effect on the biodiversity concept dimension and a medium effect on the biological conservation concept dimension.
Ocean Literacy	Mobile game	2021	Ocean	7th to 9th grades (Portugal) and Key stage three (KS3), i.e. the first three years of secondary school in the UK	The implementation of PBL points, badges, and triads can enhance learning results, particularly in fostering marine literacy among students who reside far from coastlines, where direct interaction with the ocean is uncommon. Ocean Literacy has

					contributed to the advancement of marine literacy in both nations.
ClassCraft	Web application	2021	Sustainable Mobility	Children aged 10–12 years old	Through the use of the gamified ClassCraft tool, which incorporates organized activities covering various dimensions of sustainable mobility, students gained new insights that highlighted the social and economic factors involved, and they started to cultivate an awareness of how to actively participate in behavioral change.
SDGs Board Game	Board game	2022	UN's 17 SDGs	12-60 years old	The SDGs Board Game designed by this research has an inspiring effect on learning the meaning and goals of sustainable development.
The Game of The Sea	Board game	2022	Ocean	A total of 222 players (111 children, aged 11-15 years, and 111 adults, aged 18-72 years)	Players gained extensive knowledge of the marine environment. Knowledge of the marine environment

					increases in both children and adults, with a slightly higher increase in children.
Burger.i.doo	Board game	2022	Food	Students aged 14 to 18 years old	Players have fun while learning about the impact of food on the environment and the game has a positive influence on their environmental awareness.
-	Mobile game	2022	SDGs	High school students in 12-15 age group in Greece	Students can get to know the SDGs in a purposeful and entertaining way.
BLUTUBE	Board game	2023	Sustainable water use	2nd, 3rd, and 4th grades students from the primary schools	There were reports of increased efficient water use and increased frequency of discussions with parents about water use; these positive effects were still evident after six months.

Discussion

Sustainability Content on Game Based Learning

From all the articles analysed, there are various topics related to SDGs that are taught with game-based learning, such as climate change, water resources, energy renewal, ocean, land and food. Most of the games developed from the research focused on the ocean such as

Ocean Limited, SeAdventure, The Game of The Sea, Ocean Literacy and M.O.S. (Marine, Ocean, Sea). As noted by Koenigstein et al. (2020), the significance of this issue arises from the growing threats to ocean goods and services due to human activities and climate change. The general lack of concern regarding anthropogenic climate change can be attributed to several factors, including those related to education. Education is vital for enhancing marine literacy, fostering critical thinking, and promoting citizenship skills along with democratic values (Mercer et al., 2017; Cotton & Winter, 2010). Hence, there is an immediate need to equip a diverse range of individuals with technical, social, cognitive, scientific, and civic abilities, strengthening the relationship between students and the ocean to combat the phenomenon of 'ocean blindness' (UNESCO, 2017).

The second most developed topic in the game was around climate change, alternative energy use and the 17 SDGs. According to Harker-Schuch & Watson (2019), the teaching of climate change in public secondary schools is inadequate, this is because the material is often taught separately, not integrated and not coordinated with other science topics, then the topic of climate change according to Hess & Collins (2018) is not included in the curriculum and there are many teachers who do not sufficiently understand the theoretical basis of climate change material (Plutzer et al., 2016). Furthermore, the 17 SDGs are also widely integrated into games because based on research it can increase students' awareness and understanding of sustainable development issues and SDGs and encourage the adoption of sustainable behaviour in the future. Finally, the discussion related to energy has also attracted many researchers to be developed in the form of games that can attract students. According to Phongthanachote et al. (2019) training in sustainable energy use and economical energy utilisation should start early to build more durable patterns of responsible behaviour. Given the importance of energy conservation, this energy-saving education needs to be provided at every grade level.

The Influence of Game-Based Learning on Sustainability Development

In response to the increasing demand for environmental education and awareness, more and more games are being created that contain environmental messages (Tragazikis & Meimaris, 2009). Some of the effects of implementing game based learning in sustainable development learning are:

Can create active and interactive learning

Interactive technology can educate and engage people, especially children. Virtual reality, for example, can support effective learning, particularly for young students (Latif, 2007). Physiological needs can be fulfilled through the acquisition of in-game resources, and games can increase the frequency of interactions while enhancing the sense of belonging (Vella et al., 2019).

Able to demonstrate and teach sustainability issues

Game based learning seen to be suitable for the teenage and young adult populations because they foster learning via rules, goals, rewards, and the way they promote divergent thinking (Morganti et al., 2017; Ro et al., 2017). They incorporate enjoyment, rivalry, and involvement into the intended goals, which include educating people and modifying their behavior to be more ecologically friendly (Tan & Asna, 2023).

Games also make it possible to generate a scenario where motivation, creativity, fun, interest, well-being, autonomy, and competition are promoted (Deterding, 2019; Rivera & Garden, 2021). Game-based learning (GBL) can also encourage students to learn content while playing and completing included games to promote learning (Campillo-Ferrer et al., 2020).

Improve concept understanding in students

By playing alongside or against one another, players can comprehend the demands and viewpoints of various roles through the usage of role-playing within the game (Janakiraman et al., 2021). Games and technology contribute to knowledge, participation, satisfaction, and acceptance by teachers and students (Bedwell-Torres et al., 2012; Dahalan et al., 2023). Knowledge exchange in informal environments, participation in social activities, and review of knowledge gained when participants play games. As a result, teachers can see students' progress and achievements instantly (Zhang & Yu, 2022).

Games allow players to develop empathy

Beyond simply spreading a pro-environment message, games and applications may be used

for a wide range of objectives, including helping children develop empathy for the environment and society. Games enable participants to cultivate empathy, assume various roles and viewpoints, and envision themselves in the future, thereby anticipating the outcomes of their decisions (Bachen et al, 2016). This aspect of video games is particularly beneficial in the fields of sustainability and environmental protection (Boncu et al., 2022).

Increase students' motivation

When opposed to the traditional teaching method, games contain features that appeal to people's basic motivators, which increases the urge to learn in both motivated and unmotivated students (Juan & Chao, 2015; Madani et al., 2017). One's sense of accomplishment in the game boosts their self-esteem when they complete a goal (Juan & Chao, 2015). Ultimately, games fulfill the self-actualization motivator by requiring players to use their creative thinking or problem-solving skills to achieve a goal (Madani et al., 2017). Unquestionably, games use our innate desire to their advantage to draw players in and occasionally encourage replays (Chappin et al., 2017). In this sense, incorporating enjoyable activities, inspiring, significant, and unconventional settings can boost commitment, interest, and engagement (Fonseca et al., 2023).

Games possess attributes that appeal to fundamental human motivators, inspiring driven students to engage in learning more effectively than traditional teaching methods (Juan & Chao, 2015; Madani et al., 2017). Furthermore, games necessitate the use of problem-solving or creative thinking abilities to reach objectives, satisfying the self-actualization motivator (Madani et al., 2017). Clearly, games leverage innate human motivations to entice individuals to play and, in many cases, play again (Chappin et al., 2017).

Interest in learning and positively affect their environmental awareness

As such, games are particularly adept at creating an environment where children can learn while having fun (Wang et al., 2019). Many environment-based games allow players to experience first-hand the impact of human activities on nature, these games simulate how environmental decisions such as waste management, deforestation, or infrastructure development can affect ecosystems. Thus, players learn to see the consequences of their actions on the balance of the ecosystem. Games often present environmental data and

information indirectly through gameplay, which helps players understand environmental issues such as climate change, deforestation and species extinction.

Conclusion

Considering these limitations, the use of game-based learning in sustainable development has been very beneficial. A variety of outcomes have been targeted, and the intervention brought some significant improvements, although most were short-term. Continued use of the technology seems necessary to extend its benefits in the long term. Researchers should also do the same by concentrating on developing a common methodology for developing, implementing and assessing interventions.

Recommendations

This domain study is still relatively young, and its promising results are enough to encourage further efforts to develop sustainable information, attitudes and behaviours through the use of computer games and apps.

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References

Arboleya-García, E. & Miralles, L. (2022). The Game Of The Sea: An Interdisciplinary Educational Board Game on The Marine Environment and Ocean Awareness for Primary and Secondary Students. *Education Sciences, 12*(1), 57. http://dx.doi.org/10.3390/educsci12010057

Bachen, C., Hernández-Ramos, P., Raphael, C., & Waldron, A. (2016). How Do Presence, Flow, and Character Identification Affect Players' Empathy and Interest in Learning from a Serious Computer Game?. *Computers in Human Behaviour, 64*(3), 77–87.

http://dx.doi.org/10.1016/j.chb.2016.06.043

Bazan, E. J. (1976). Environmental Simulation Games. *Journal of Environmental Education, 8*, 41–51. https://doi.org/10.1080/00958964.1976.9941564

Bedwell-Torres, W. L., Pavlas, D., Heyne, K., Lazzara, E., & Salas, E. (2012). Toward A Taxonomy Linking Game Attributes to Learning: An Empirical Study. *Simulation & Gaming, 43*(6), 729–760. http://dx.doi.org/10.1177/1046878112439444

Bilancini, E., Boncinelli, L., & Di Paolo, R. (2023). Game-Based Education Promotes Practices Supporting Sustainable Water Use. *Ecological Economics, 208*, 107801. https://doi.org/10.1016/j.ecolecon.2023.107801

Boncu, S., Candel, O., & Popa, N. L. (2022). Gameful Green: A Systematic Review on the Use of Serious Computer Games and Gamified Mobile Apps to Foster Pro-Environmental Information, Attitudes and Behaviors. *Sustainability, 14*(16), 10400. http://dx.doi.org/10.3390/su141610400

Campillo-Ferrer, J., Martínez, P. M., & Ibáñez, R. S. (2020). Gamification in Higher Education: Impact on Student Motivation and The Acquisition of Social and Civic Key Competencies. *Sustainability, 12*(12), 4822. http://dx.doi.org/10.3390/su12124822

Chappin, E. J. L., Bijvoet, X., & Oei, A. (2017). Teaching Sustainability to A Broad Audience Through An Entertainment Game-The Effect of Catan: Oil Springs. *Journal of Cleaner Production, 156*, 556–568. https://doi.org/10.1016/j.jclepro.2017.04.069

Chen, F-H., & Ho, S-J. (2022). Designing A Board Game about The United Nations' Sustainable Development Goals. *Sustainability, 14*(18), 11197. https://doi.org/10.3390/su141811197

Cheng, P-H., Yeh, T-K., Tsai, J-C., Lin, C. R., & Chang, C. Y. (2019). Development of an Issue-Situation-Based Board Game: A Systemic Learning Environment for Water Resource Adaptation Education. *Sustainability, 11*(5), 1341. http://dx.doi.org/10.3390/su11051341

Cordova, D. I., & Lepper, M. (1996). Intrinsic Motivation and the Process of Learning: Beneficial Effects of Contextualization, Personalization, and Choice. *Journal of Educational Psychology, 88*(4), 715–730. http://dx.doi.org/10.1037/0022-0663.88.4.715

Cotton, D. R. E., & Winter, J. (2010). *It's Not Just Bits of Paper and Light Bulbs': A Review of Sustainability Pedagogies and Their Potential for Use in Higher Education.* In Sustainability Education: Perspectives and Practice Across Higher Education, edited by S. Sterling. London: Earthscan.

Crohn, K., & Birnbaum, M. (2010). Environmental Education Evaluation: Time to Reflect, Time for Change. *Evaluation and Program Planning*, *33*(2), 155–158. http://dx.doi.org/10.1016/j.evalprogplan.2009.07.004

Dahalan, F., Alias, N., & Shaharom, M. S. N. (2023). Gamification and Game Based Learning for Vocational Education and Training: A Systematic Literature Review. *Education and Information Technologies*, *29*(3), 1–39. https://doi.org/10.1007/s10639-022-11548-w

Deci, E. L., Koestner, R. & Ryan, R. M. (2001). Extrinsic Rewards and Intrinsic Motivation in Education: Reconsidered Once Again. *Review of Educational Research, 71*(1), 1–27. https://doi.org/10.3102/00346543071001001

Deterding, S. (2019). Gamification in Management: Between Choice Architecture and Humanistic Design. *Journal of Management Inquiry*, *28*(10). http://dx.doi.org/10.1177/1056492618790912

Fjællingsdal, K., & Klöckner, C. A. (2019). Gaming Green: The Educational Potential of Eco-A Digital Simulated Ecosystem. *Frontiers in Psychology, 10*. http://dx.doi.org/10.3389/fpsyg.2019.02846

Fonseca, C., Pettitt J., Woollard, A., Rutherford, A., Bickmore, W., Ferguson-Smith, A., & Hurst, L. D. (2023). People with More Extreme Attitudes Towards Science Have Self-Confidence in Their Understanding of Science, Even If This Is Not Justified. *PLoS Biol, 21*(1). https://doi.org/10.1371/journal.pbio.3001915

Harker-Schuch, I., & Watson, M. (2019). *Developing a Climate Literacy Framework for Upper Secondary Students.* In: Leal Filho, W., Hemstock, S. (eds) Climate Change and the Role of Education. Climate Change Management. Springer, Cham. https://doi.org/10.1007/978-3-030-32898-6_17

Harker-Schuch, I., Mills, F. P., Lade, S. J., & Colvin, R. M. (2020). CO_2peration-Structuring A 3D Interactive Digital Game to Improve Climate Literacy in the 12-13-Year-Old Age Group. *Computers & Education*, *144*, 103705. https://doi.org/10.1016/j.compedu.2019.103705

Hess, D. J., & Collins, B. M. (2018). Climate Change and Higher Education: Assessing Factors That Affect Curriculum Requirements. *Journal Of Cleaner Production, 170*, 1451–1458. https://doi.org/10.1016/j.jclepro.2017.09.215

Janakiraman, S., Watson, S. L., Watson, W. R. & Newby, T. J. (2021). Effectiveness of Digital Games in Producing Environmentally Friendly Attitudes and Behaviors: A

Mixed Methods Study. *Computers & Education, 160*(1), 104043. http://dx.doi.org/10.1016/j.compedu.2020.104043

Juan, Y-K., & Chao, T-W. (2015). Game-Based Learning for Green Building Education. *Sustainability, 7*(5), 5592–5608. https://doi.org/10.3390/su7055592

Kilanioti, I. (2022). Teaching a Serious Game for the Sustainable Development Goals in the Scratch Programming Tool. *European Journal of Engineering and Technology Research. Special Issue: CIE 2022*. http://dx.doi.org/10.24018/ejeng.2022.1.CIE.2957

Koenigstein, S., Hentschel, L-H., & Heel, L. C., & Drinkorn, C. (2020). A Game-Based Education Approach for Sustainable Ocean Development. *ICES Journal of Marine Science, 77*, 1629–1638. http://dx.doi.org/10.1093/icesjms/fsaa035

Korte, T., Otte, L., Amel, H., & Beeken, M. (2022). "Burger.i.doo"-An Innovative Education Game for the Assessment of Sustainability from Meat and Substitute Products in Science Education. *Sustainability, 15*(1), 213. http://dx.doi.org/10.3390/su15010213

Latif, R. A. (2007). Understanding Malaysian Students as Gamers: Experience. *Proceedings of the 2nd International Conference on Digital Interactive Media in Entertainment and Arts, 19 September 2007*. New York United States, Association of Computing Machinery.

Leeming, F. C., Dwyer, W. O., Porter, B. E., & Cobern, M. K. (2010). Outcome Research in Environmental Education: A Critical Review. *The Journal of Environmental Education, 24*(4), 8–21. https://doi.org/10.1080/00958964.1993.9943504

Leitão, R., Maguire, M., Turner, S., Arenas, F., & Guimarães, L. (2021). Ocean Literacy Gamified: A Systematic Evaluation of The Effect of Game Elements on Students' Learning Experience. *Environmental Education Research, 28*(4). http://dx.doi.org/10.1080/13504622.2021.1986469

Lin, Y-L., Huang, S. W., Chang, C-C. (2019). The Impacts of A Marine Science Board Game on Motivation, Interest, and Achievement in Marine Science Learning. *Journal of Baltic Science Education, 18*(6), 907–923. http://dx.doi.org/10.33225/jbse/19.18.907

Lubchenco, J. (1998). Entering the Century of the Environment: A New Social Contract for Science. *Science, 279* (5350), 491–497. http://dx.doi.org/10.1126/science.279.5350.491

Madani, K., Pierce, T.W., & Mirchi, A. (2017). Serious Games on Environmental Management. *Sustainable Cities and Society, 29*(2), 1–11. http://dx.doi.org/10.1016/j.scs.2016.11.007

Martín-Lara, M. A., & Calero, M. (2020). Playing a Board Game to Learn Bioenergy and Biofuels Topics in an Interactive, Engaging Context. *Journal of Chemical Education, 97*(5). http://dx.doi.org/10.1021/acs.jchemed.9b00798

Mercer, T. G., Kythreotis, A. P., Robinson, Z. P., Stolte, T., George, S., & Haywood. S. K. (2017). The Use of Educational Game Design and Play in Higher Education to Influence Sustainable Behaviour. *International Journal of Sustainability in Higher Education, 18*(3), 359–384. http://dx.doi.org/10.1108/IJSHE-03-2015-0064

Miller, J. L., Wentzel, M. T., Clark, J. H., & Hurst, G. A. (2019). Green Machine: A Card Game Introducing Students to Systems Thinking in Green Chemistry by Strategizing the Creation of a Recycling Plant. *Journal of Chemical Education, 96*(12), 3006–3013. http://dx.doi.org/10.1021/acs.jchemed.9b00278

Morganti, L., Pallavicini, F., Cadel, E., Candelieri, A., Archetti, F., & Mantovani, F. (2017). Gaming for Earth: Serious Games and Gamification to Engage Consumers in pro-Environmental Behaviours for Energy Efficiency. *Energy Research & Social Science, 29*, 95–102. http://dx.doi.org/10.1016/j.erss.2017.05.001

Neset, T-S., Andersson, L., Uhrqvist, O., & Navarra, C. (2020). Serious Gaming for Climate Adaptation-Assessing the Potential and Challenges of a Digital Serious Game for Urban Climate Adaptation. *Sustainability, 12*(5), 1789. http://dx.doi.org/10.3390/su12051789

Ouariachi, T., Olvera-Lobo, M.D., & Gutiérrez-Pérez, J. (2019). *Serious Games and Sustainability*. In: Leal Filho, W. (Ed.) Encyclopedia of Sustainability in Higher Education. Cham: Springer International Publishing. http://dx.doi.org/10.1007/978-3-319-63951-2_326-1

Parrondo, M., Rayon-Viña, F., Borrell, Y. J., & Miralles, L. (2021). Sustainable Sea: A Board Game for Engaging Students in Sustainable Fisheries Management. *Applied Environmental Education & Communication, 20*(4), 406–421. https://doi.org/10.1080/1533015X.2021.1930608

Phongthanachote, C., Rattanadecho, P., Com-arch, C., & Prommas, R. (2019). Animation and Computer Games Design to Build Awareness of Energy Conservation. *Science & Technology Asia, 24*(1), 21–29. https://ph02.tci-thaijo.org/index.php/SciTechAsia/article/view/171199

Plutzer, E., Mccaffrey, M., Hannah, A. L., Rosenau, J., Berbeco, M., & Reid, A. H. (2016). Climate Confusion among U.S. Teachers. *Science, 351*(6274), 664–665. https://doi.org/10.1126/science.aab3907

Rivera, E., & Garden, C. (2021). Gamification for Student Engagement: A Framework. *Journal of Further and Higher Education, 45*(4), 1–14. http://dx.doi.org/10.1080/0309877X.2021.1875201

Ro, M., Brauer, M., Kuntz, K., Shukla, R., & Bensch, I. (2017). Making Cool Choices for Sustainability: Testing the Effectiveness of a Game-Based Approach to Promoting pro-Environmental Behaviors. *Journal of Environmental Psychology, 53*, 20–30. https://doi.org/10.1016/j.jenvp.2017.06.007

Saitua-Iribar, A., Corral, J., & Pena, N. (2020). Improving Knowledge about the Sustainable Development Goals through a Collaborative Learning Methodology and Serious Game. *Sustainability, 12*(15), 6169. http://dx.doi.org/10.3390/su12156169

Sipone, S., Abella-García, V., Rojo, M., & Dell'Olio, L. (2021). Using ClassCraft to Improve Primary School Students' Knowledge and Interest in Sustainable Mobility. *Sustainability, 13*(17). http://dx.doi.org/10.3390/su13179939

Stanitsas, M., Kirytopoulos, K., & Vareilles, E. (2019). Facilitating Sustainability Transition through Serious Games: A Systematic Literature Review. *Journal of Cleaner Production, 208*, 924–936

Swacha, J., Maskeliunas, R., Damaševicius, R., Kulikajevas, A., Blažauskas, T., Muszynska, K., Miluniec, K., & Kowalska, K. (2021). Introducing Sustainable Development Topics into Computer Science Education: Design and Evaluation of the Eco JSity Game. *Sustainability, 13*(8), 4244. https://doi.org/10.3390/su13084244

Swinerton, E. N. (1972). Environmental Gaming Simulations. *The Journal of Environmental Education, 3*, 49–52. https://doi.org/10.1080/00958964.1972.10801683

Tan, C. K. W., & Asna, H. N. (2023). Serious Games for Environmental Education. *Integrative Conservation, 2*(1), 19–42. http://dx.doi.org/10.1002/inc3.18

Tragazikis, P., & Meimaris, M. (2009). Engaging Kids with the Concept of Sustainability Using A Commercial Video Game - A Case Study. *Lecture Notes in Computer Science, 3*(5940), 1–12. http://dx.doi.org/10.1007/978-3-642-11245-4_1

Tsai, J-C., Liu, S-Y., Chang, C-Y., & Chen, S-Y. (2021). Using A Board Game to Teach about Sustainable Development. *Sustainability, 13*(9), 4942. https://doi.org/10.3390/su13094942

UNESCO. (2017). Ocean Literacy for All. A Toolkitz, Unesco Publishing. Accessed: Sept. 16, 2024. [Online]. Available: http://unesdoc.unesco.org/images/0026/002607/260721E.pdf

Uribe, R. V., & Cobos, S. A. U. (2014). Board Games as Tool for Teaching Basic Sustainability Concepts to Design Students. *The European Conference on Sustainability, Energy & the Environment.*

Vella, K., Johnson, D., Cheng, V. W. S., Davenport, T., Mitchell, J., Klarkowski, M., & Phillips, C. (2019). A Sense of Belonging: Pokémon GO and Social Connectedness. *Games and Culture*, *14*(6), 583–603. http://dx.doi.org/10.1177/1555412017719973

Veronica, R., & Calvano, G. (2020). Promoting Sustainable Behavior Using Serious Games: Seadventure for Ocean Literacy. *IEEE Access*. *8*, 196931–196939. http://dx.doi.org/10.1109/ACCESS.2020.3034438 \

Wang, C-H., Wu, K., & Tsau, S-Y. (2019). Flow Learning Experience: Applying Marketing Theory to Serious Game Design. *Journal of Educational Computing Research*, *57*(4), 417–447. http://dx.doi.org/10.1177/0735633117752454

Zhang, Q., & Yu, Z. (2022). Meta-Analysis on Investigating and Comparing the Effects on Learning Achievement and Motivation for Gamification and Game-Based Learning. *Education Research International*, 1–9. https://doi.org/10.1155/2022/1519880

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Chapter 2 - Exploring the Landscape: A Systematic Review of the Tamil Reading Development Framework

Naina Mohamed Mohamed Safeek, Kartheges Ponniah

Chapter Highlights

- Reading exerts a profound and lasting influence on children's lives, commencing in early childhood and extending throughout their entire lifespan.
- While the science of reading has predominantly drawn upon research conducted in English and other languages, the application of certain reading framework components to Tamil language-based instruction poses challenges.
- Tamil possesses unique linguistic features that diverge from English and Western languages. In response, this study aims to introduce a Smart Reading Module-based (SRM) teaching intervention designed for Tamil children, whether they encounter reading difficulties or not.
- To formulate this intervention, the researcher conducted an extensive systematic review, encompassing 90 empirical studies conducted between 2016 and 2023, all endorsing skill-based interventions targeting reading development.
- The findings robustly support the efficacy of the SRM-based teaching intervention model in cultivating reading fluency among children, especially those grappling with reading challenges.
- This comprehensive intervention encompasses critical elements, including phonological awareness, word-sound mapping, syllabic and morphological comprehension, syntactic understanding, semantic proficiency, and adeptness in reading comprehension.
- By accommodating the distinct linguistic characteristics of the Tamil language, this SRM-based approach strives to empower Tamil children on their journey towards becoming proficient and confident readers.

Introduction

The Reading comprehension is the main goal, where the objective is to understand the meaning that the written text is trying to convey. Consequently, the focus of reading development should revolve around establishing a framework that enables children to construct an understanding of printed material. The foundation of reading is knowledge acquisition, cultural engagement, democratic participation, and career success (Castles et al., 2018). Reading literacy assumes a pivotal role in people's daily routines (Britt et al., 2018).

Reading holds fundamental importance in our lives, as it is essential for survival, and any hindrance in acquiring literacy skills can significantly impede individual, societal, and national progress (Khateb & Bar-Kochva, 2018). Proficient readers possess the capacity to extract meaning from text both accurately and efficiently, underscoring the value of reading competence (Petscher et al., 2019). The problem of illiteracy or difficulties acquiring literacy skills has become a critical concern in our society that is becoming more and more reliant on technology (Joshi & McBride, 2019). Addressing these challenges in literacy acquisition is paramount to ensuring individual and collective progress in the modern world.

Literature

Reading Development

Empirical research and reading science both explain the reading process. The children approach the task of learning to read with significant inter-individual differences in vocabulary, phonology, and orthographic skills, so understanding the learning-to-read process is crucial before developing the interventions (Ziegler et al., 2020). Children's reading abilities vary from person to person, just like their performance on other tasks. While research can help educators better understand how children learn and how written language functions, researchers cannot eliminate these differences between students (Treiman, 2018).

Phonology, morphology, syntax, semantics, and other language aspects are all involved in the highly complex process of reading; mastery of these areas of language is correlated with early development (Jasińska & Petitto, 2017). Beginning readers pick up on sound-symbol correlations and learn how to sound out words by gathering the sounds of all the letters, going from left to right, and combining them to form a word (Mather & Jaffe, 2021). In order to

read words from memory, beginning readers combine their different identities—orthographic, phonological, morphological, syntactic, and semantic identities—to create single lexical units in memory (Ehri, 2020). In contrast, the Simple View of Reading (SVR) (Hoover & Gough, 1990) views reading as a simple process that results from linguistic comprehension and decoding ability. This explanation made it easy to understand the reading process and develop reading frameworks.

Children who struggle with reading acquisition should receive effective reading interventions (Schmitterer & Brod, 2021). Teaching reading skills requires a complex mental process that involves experiencing, predicting, verifying, and acknowledging information based on the readers' prior knowledge, experience, and information (Paul & Christopher, 2017). An early reading program specifically addresses the orthographic, morpho-semantic, syntactic, and metalinguistic levels of the language within a language-focused framework for literacy instruction (Mathur & Nag, 2019).

Studies on reading development underscore several key elements and skill-based intervention models critical for achieving reading proficiency. The importance of phonemic awareness, phonics, fluency, vocabulary, and comprehension as critical reading skills has been highlighted by the National Reading Panel (NRP, 2000). Three elements of word knowledge are proposed by the Supermodel of Literacy Development: meaning, spoken language sound structure, and written language letters (Breadmore et al., 2019).

Furthermore, the International Dyslexia Association (IDA, 2019) has advocated for a comprehensive approach to reading comprehension, encompassing various elements such as phonological awareness, sound-symbol association, syllable instruction, morphological awareness, syntactic awareness, and semantic awareness. According to Moats (2019), structured literacy is very beneficial, especially for students who have very difficult time learning to read and spell printed words. Structured literacy includes phonological awareness, sound-symbol association, orthography/syllable instruction, morphology, syntax, and semantics.

However, it's worth noting that the implications of these established frameworks may not align perfectly with studies focused on the fluency development of Tamil-speaking children

encountering reading difficulties. Tailoring reading interventions to the unique linguistic characteristics of the Tamil language may require a nuanced approach.

Reading Frameworks and Tamil Language

Reading War focuses on reading development and aims to help kids who have reading difficulties by suggesting reading frameworks and different skills or components of reading development. All writing systems are essentially codes for spoken language, and children must decipher the code specific to their language in order to learn to read. The code differs from language to language (Castles et al., 2018).

The Tamil language has distinctive features that set it apart from English or other Western languages. Reading and writing studies have historically concentrated on a small group of European languages, especially English (Winskel, 2013). Tamil is one of the about 26 indigenous languages of the Indian subcontinent that make up the Dravidian language family, which is divided into its southern branch (Bhuvaneshwari & Padakannaya, 2013).

Though the phrasal order in Tamil is flexible, the language is consistently verb-final, with the verb appearing at the end of the clause and the typical word order of subject, object, and verb. The learners encounter difficulties with the word arrangement, particularly with the non-cognate group (Shakunthala, 2017). Tamil is a post-positional inflectional language with rich morphology; it is an agglutinative language in which suffixes make up the majority of the categories expressed (Rekha et al., 2012).

Some components of the reading frameworks do not comply with Tamil languages, and the Tamil language-based reading development framework was not created to help Tamil children who have reading difficulties. Traditional teaching strategies are used to develop Tamil language proficiency; however, these strategies are not focused on the development of children who have reading difficulties or reading-related difficulties. To identify the crucial abilities for SRM-based teaching reading to Tamil children with reading difficulties, this review is theoretically oriented with the SVR theory. Decoding and linguistic comprehension from the SVR are used to report a framework for teaching reading that is based on SRM and is meant for Tamil language reading development programs.

SRM Conceptual Framework

This teaching intervention model, based on the Smart Reading Module (SRM), was designed to enhance SVR-based decoding and linguistic comprehension. It also aimed to establish a conceptual framework for module-based teaching interventions in the context of reading development for Tamil children, whether they face reading difficulties or not. The SRM approach focuses a lot of emphasis on the idea that reading development is a process of gradually deriving meaning from text, which is accomplished by developing different components in a methodical way. Within this framework, the researchers constructed a comprehensive teaching model that harnesses linguistic abilities such as phonological awareness, sound-symbol association, syllable identification, and morphology. These elements were strategically employed to foster the development of decoding skills, while simultaneously nurturing syntactic, semantic, and comprehension abilities to enhance linguistic comprehension. It is noteworthy that the enhancement of one subcomponent can positively influence the enhancement of another subcomponent either directly or indirectly, indicating the interdependence of these aspects of reading development (Nation, 2019). The conceptual model of the SRM is shown in Figure 1.

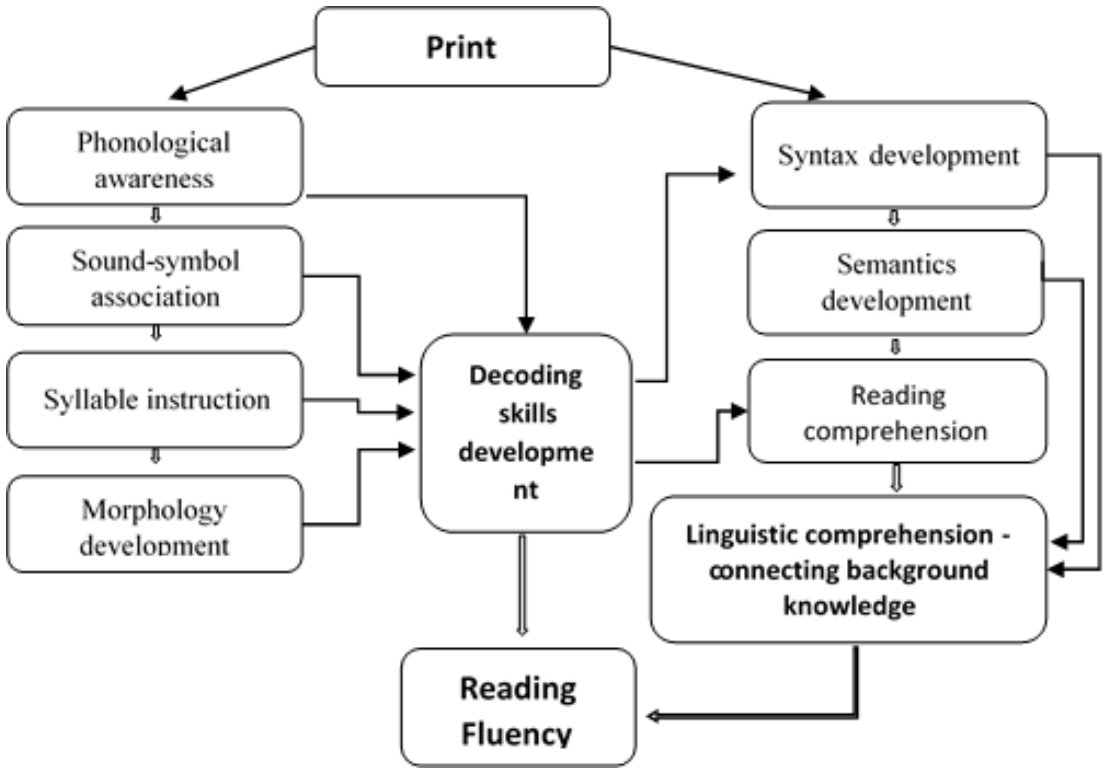

Figure 1: The conceptual model for SRM.

Aim of the study

This study aims to introduce a reading instruction framework grounded in the (SVR), specifically designed for Tamil language reading programs. The framework utilizes SVR's key components, focusing on decoding and linguistic comprehension.

Methodology

This study serves as a foundational exploration into the pedagogy of teaching reading to Tamil children encountering reading challenges. The research adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Page et al., 2021) guidelines to structure this comprehensive review. The review's scope includes empirical studies on reading development as well as studies that look at reading development components entwined with the nuances of Tamil language within different English-language reading frameworks.

However, it's important to clarify that this review does not encompass aspects of language development such as print awareness and writing skills. The selection of empirical studies within the review is confined to the timeframe spanning from 2016 to 2023.

This timeframe ensures that the research encompasses contemporary findings and insights relevant to the teaching of reading to Tamil children, particularly those who encounter challenges in this domain. Figure 2 displays the inclusion and exclusion criteria for the review.

The researchers conducted an exhaustive search for scholarly materials encompassing full articles and book chapters. This search was carried out across reputable platforms, including Google Scholar, Research Gate, ScienceDirect, and Wiley's online library. To facilitate a comprehensive exploration of the subject matter, a set of keywords was employed, including "science of reading," "reading development," "reading frameworks," "Simple View of Reading," "Tamil reading development," and "Tamil language development." In total, this search yielded 136 empirical study articles within the field.

Following a meticulous screening process, specific criteria were applied to filter the results.

Consequently, duplicate articles (n=6), conference proceedings (n=4), articles that did not align with the study's objectives (n=12), outdated articles (n=14), articles lacking publication year details (n=2), and articles not written in English (n=8) were excluded from consideration. After rigorous evaluation, 90 articles were deemed suitable for inclusion in the review based on their relevance and applicability to the research topic. These selected articles were then obtained in their entirety, and their relevance to the study was further assessed by examining their titles, abstracts, and findings.

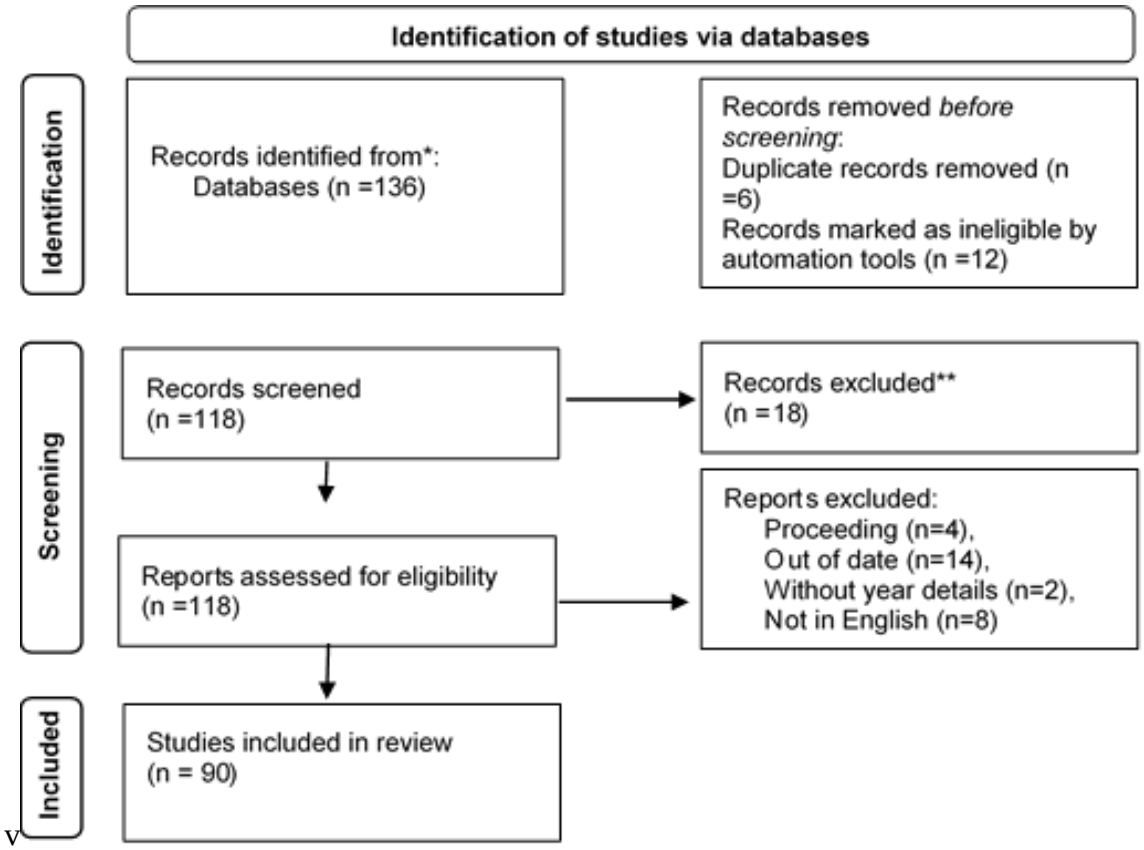

Figure 2: Flow chart of the inclusion and exclusion criteria. Adapted from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Page et al., 2021).

The selected articles underwent an additional quality assessment, ensuring they were well-crafted, inclusive of proper citations, and indexed appropriately. Within this comprehensive review, a primary emphasis was placed on empirical articles that substantiated skills-based interventions and proposed essential skills about the science of reading.

Data extraction was meticulously conducted in adherence to the systematic review methodology. This approach aimed to furnish a comprehensive overview of the empirical

findings associated with skills-based interventions designed to enhance reading fluency. Throughout this process, the researchers upheld a commitment to neutral reporting, diligently avoiding any biased interpretations.

Findings

Phonological Awareness

Understanding the smallest, mostly meaningless units of sound in a language—that is, knowing that words have syllables, rhymes, and phonemes is known as phonological awareness, a metalinguistic skill connected to reading proficiency (Bishara, 2020). Tamil, which has several spoken varieties, is the only language that has phonological awareness. Since several early-acquired Tamil words end in closed syllables that can only be written using a phonemic Akshara, the early introduction of the phonemic consonant is helpful to initiate the reading of authentic texts. Tamil is a strongly diglossic language, and apparent differences among scholars in their account of the phonology of the language are primarily because of the form described (Nag & Narayanan, 2019). Tamil vowels are divided into two categories: short (Kuril) and long (Netil). There are five short vowels and seven long vowels, including two diphthongs. Three categories of consonants—hard, soft, and medium—have six consonants each, for a total of 18 consonants. The combination of vowels and consonants results in 216 compound characters, plus one additional special letter, aytham (∴). The standard Tamil alphabet has 247 characters (Thangarajan et al., 2009).

Young readers' development depends on phonological awareness. This is because phonological awareness enhances our understanding of how words in our language are printed (Kanapathy, 2019). Combining different words, learning the allophonic rules, word segmentation, the task of identifying words, and tracking the statistical distributions of sounds and syllables help children develop phonological awareness (Lidz & Perkins, 2018).

Studies on this topic indicate that phonological awareness, which also predicts the development of reading, has a significant impact on the early stages of reading development. The phonological awareness and naming speed are significant and unique predictors (Tibi & Kirby, 2018), later reading ability (Erskine et al., 2020), early reading at word level between the ages of 4 and 6 (Cunningham et al., 2021), enhanced spelling and word decoding abilities in first grade, and that this beneficial development extended to enhanced decoding abilities,

which enhanced reading comprehension in subsequent grades (Kjeldsen et al., 2019), and that when lesson plans provide ample opportunity for students to pair verbal labels with letter forms, it is advantageous to teach letter sounds before letter names (Roberts et al., 2019). Rapid naming was a significant predictor of automatic word recognition and comprehension, whereas phonological awareness was a significant predictor of decoding. However, relying too heavily on phonological awareness composites could mask task-specific issues that are hurting a child's reading ability (Mundy & Hannant, 2020).

Training in phonological awareness is important for improving reading abilities. The impact of the intervention on kids' letter knowledge and phonological awareness (Pfost et al., 2019), the considerably moderate relationship in Spanish-speaking children's reading tasks and phonological awareness (Villanueva-Villar et al., 2021), at the post-test on the overall composites of phonological processing, the intervention group showed a higher use of phonological awareness (Hodgins & Harrison, 2021), following the intervention, the children in the experimental condition made significantly more progress than the control group in terms of phonological awareness, alphabet knowledge, non-word reading, and spelling (Kelly et al., 2019), children with higher levels of education typically experience phonemic awareness development concurrent with syllabic awareness development (Cárnio et al., 2017), and the benefits of print knowledge and phonological awareness for the development of reading comprehension and decoding skills (Layes et al., 2020).

Research on phonological awareness that encompassed additional abilities demonstrated a noteworthy enhancement in the development of reading skills. Phonological awareness and early reading skills are enhanced by early phonological instruction (Wolff & Gustafsson, 2022), acquiring a lexicon and orthography, as well as developing reading comprehension, are all correlated with increasing phonological and morphological awareness (Bishara, 2020), reading comprehension is enhanced by language intervention programs that incorporate phonological, morphological, and semantic exercises (Lyster et al., 2021), and both synthetic and analytic phonics are useful techniques for teaching beginning and struggling readers how to read words (Henbest & Apel, 2017).

Sound-Symbol Association

The sound-symbol association called phoneme-grapheme mapping takes place next to

phonology learning. Phonological development helps children to identify sounds and associate them with letters and symbols. Learning letter-sound association, or letter knowledge, in alphabetic scripts is an essential first step toward learning to read and a reliable indicator of future reading abilities (Plewko et al., 2018). One of the most important aspects of early literacy development is learning the correspondences between letters and sounds (Sunde et al., 2019). Orthographic mapping is the process of associating pronunciations with the written letters that correspond to those pronunciations in memory in order to store written words for later instant recall (Miles & Ehri, 2019).

Labels are available for intra-symbol elements in Tamil, and the language has a rich vocabulary for sets of symbols in orthography (Nag & Narayanan, 2019). The Tamil script is an alpha-syllabary that is a part of the Brahmi script family (Joshi & McBride, 2019). The complicated orthographic mapping with sounds in Tamil is essential, which may help in paired association, backward recall, and word recognition, linking visual and sound elements, word identification, and multi-syllable reading.

Training is most effective when kids struggle with reading, according to empirical studies on sound-symbol associations. The orthographic and sound mapping instructions are effective, that help the children to efficient word reading. The group of letters to syllables increases more as a result of phonemic awareness intervention than the group of letters to phonemes (Vazeux et al., 2020), phonics teaching impacts positively word reading development (Flynn et al., 2021), word spelling and word and pseudo-word reading efficiency (Van Rijthoven et al., 2020), Chinese word reading was aided by paired associate learning (Liu et al., 2020), poor spelling, letter-sound knowledge, phonological output, and poor reading accuracy for regular words, non-words, and irregular words can all be effectively treated with phonics training (McArthur et al., 2018), and the majority of kids in the experiment and control groups were able to learn the new correspondences between letters and sounds in speech in the allocated amount of time (Law et al., 2018).

Research on the relationship between sound and symbol results in the development of decoding, which foreshadows the eventual development of reading. The sound-symbol paradigm proved to be a significant predictor of subsequent reading success in a language where spelling-to-sound relationships are statistically stable (Horbach et al., 2018), students' reading progress is aided by remediation sessions that concentrate on written word

identification (Gallet et al., 2020), when it came to word reading, spelling, decoding, and grapheme-phoneme correspondences, the kids who got mixed instruction performed better (Vadasy & Sanders, 2020), and grapheme-phoneme decoding training was far more successful in helping novices read consonant-vowel syllables, multisyllabic words, and pseudo words than both whole-syllable decoding and individual grapheme-phoneme instruction (Sargiani et al., 2021).

Syllable Instruction

The process of developing reading skills includes instruction in spelling and orthography. Spelling is significant because of its role in successful reading and writing, and orthographic knowledge plays a significant part in both reading and spelling (International Literacy Association, 2019). Knowledge of spelling and orthography serves as the fundamental basis for the quick and effective encoding and decoding of words, giving people more time to reflect and plan as they write and read (Templeton, 2020). Strong mental representations of words—including their spellings, meanings, and pronunciations—are essential for efficient word identification. Orthographic learning is the process through which individual word spellings are learned (Ginestet et al., 2020).

The Tamil language has difficult characteristics like agglutination and morpho-phonology. In Tamil, there is a special feature called a prosodic syllable (asai). The prosodic syllabic representation in the Tamil language consists of the combinations of short vowels, long vowels, and consonants. A syllable is a larger unit than a phone, so it addresses the severe contextual variations between phones within it (Thangarajan et al., 2009). Since mastery of the Tamil akshara system is required at multiple levels and learning the large number of symbols in Tamil is expected to take some time, it is an especially interesting system for studying spelling development (Nag & Narayanan, 2019). When a sequence of vocoids follows an onset consonant, the consonant and the first vocoid are represented by a single letter, and the second vocoid, as in words, is denoted by a separate letter in the Tamil spelling system. In other words, the onset of syllables and the subsequent vowel are indicated by a single letter, regardless of the length of the vowel (Srinivas & Ganesh Kumar, 2018).

Syllable teaching and the development of reading fluency were found to be closely related in empirical studies based on literacy development. Phonological awareness and letter naming

were important indicators of spelling knowledge (Paige et al., 2018), orthographic knowledge is believed to support both literacy skills and to have a strong developmental correlation with reading and spelling abilities (Gangl et al., 2018), spelling was more frequently and earlier predicted by orthographic knowledge than by reading (Querido et al., 2021), previous reading indicated the spelling that would follow (Georgiou et al., 2019), beyond tests of phonological awareness, letter-sound knowledge, and other skills prior to Grade 1, post-kindergarten spelling was typically a significant predictor of word reading ability in subsequent grades (Treiman, et al., 2019), and the primary source of decoding's contribution to reading comprehension is accurate word reading (Ho et al., 2017).

The orthographic and sound mapping intervention has a positive effect on how well children read. Enhancing the word recognition abilities of struggling readers through syllable-based reading intervention is a promising strategy (Müller et al., 2020), the dyslexic children's intervention resulted in a decrease in all error types (Van Rijthoven et al., 2021), reducing moments of frustration and increasing the child's motivation to read as they get closer to proficient reading in terms of reading performance metrics like speed and comprehension (Lunte & Boll, 2020), orthographic learning predicted word reading directly (Mimeau et al., 2018), orthographic similarity helped adults and kids read silent sentences without preprocessing (Milledge et al., 2022), and the development of language reading was contingent upon the attainment of a superior orthographic lexicon and print-to-sound mapping (Siok & Tan, 2022). Additionally, Galuschka, et al.'s (2020) comprehensive review and meta-analysis found that spelling performance was significantly impacted by treatment approaches that included phonics, orthographic, and morphological instruction.

Morphological Awareness

The smallest units of meaning from which new words are formed in any given language are called morphemes (Deacon et al., 2019). The basic building blocks that encode meaning are morphemes, which are the smallest units of meaning in a language. Morphological skills allow for the efficient use of morphemes in both oral and written language. Morphological awareness affects the indirect pathways through which morphological analysis and decoding occur during reading to support children's comprehension of what they read (Levesque et al., 2020).

Tamil morphology is quite different from English which includes several thousands of the word stems. Tamil stands out due to its morphological richness, with its agglutinating nature making it especially intriguing (Sarma, 2014). In Tamil, nouns and verbs exhibit simplicity or complexity, varying according to their meanings. Adjectives and adverbs can be formed through derivation, and the language features numerous instances of compounding (Nag & Narayanan, 2019).

The word forms in Tamil are long and consist of two to as many eight or nine or more (Sakkan, 2017). Tamil possesses a wealth of morphological intricacies and follows a relatively flexible word order. It adopts an (Subject) Object-Verb (S-OV) structure with a preference for left-branching constructions (Krishnamurthy & Sarveswaran, 2021). Tamil is characterized by its morphological richness and utilizes an agglutinative grammar structure. This involves the use of suffixes to indicate various grammatical features such as noun class, number, case, and verb tense. The language exhibits flexibility in word order, though it typically leans towards a subject–object–verb (SOV) arrangement (Winskel, 2020).

Children's language skills in this language are nurtured through the development of morphological awareness, which plays a crucial role in predicting their proficiency in reading, spelling, and reading comprehension. The longitudinal predictors of reading and spelling abilities from preschool to the end of the first grade include both morphological and phonological awareness skills (Diamanti et al., 2017), morphology plays distinctive roles in shaping language and influencing literacy outcomes, exhibiting stronger connections to specific aspects of literacy (Goodwin et al., 2020), the language skills acquired during preschool not only have direct impacts but also exert long-range effects, both directly and indirectly, on the development of reading comprehension (Lyster et al., 2020), in German, spelling proficiency is a more accurate predictor than reading fluency (Görgen et al., 2021), additionally, it serves as a significant predictor for both reading and spelling, especially when dealing with multisyllabic words (Enderby et al., 2021).

The development of morphology is greatly aided by the intervention focusing on sight words, high-frequency words, and multi-syllabic words. Enhancing morphological awareness has shown positive outcomes, including improved reading fluency and accuracy, and a notable shift in reading level according to national norms (Vaknin-Nusbaum, 2021). This improvement holds promise as an effective intervention method for children facing reading

difficulties (Georgiou et al., 2020). Additionally, research indicates a correlation between reading comprehension and derivational morphology, with the distributional aspect showing the strongest correlation (Amirjalili & Jabbari, 2018). Furthermore, the teaching of morphological skills has been proven to significantly enhance overall reading proficiency (Rothou & Padeliadu, 2019).

Furthermore, it's important to have a strong sight vocabulary. Sight words. Being able to read high-frequency words with automaticity provides a significant boost in early reading (Anderson & Scanlon, 2020), the correlation between morphological fluency and morphological awareness for pseudo-words was observed across all grades, showing a connection with both reading and spelling skills (Haase & Steinbrink, 2022). Additionally, there is an emphasis on promoting morphological awareness and prosodic fluency to encourage more profound and meaningful interactions between students and texts (Bart-Addison & Griffin, 2021).

Syntactic Development

Syntax refers to the set of principles governing the arrangement and role of words in a sentence to convey meaning. Learning syntax facilitates the transformation of short, disjointed sentences into longer, grammatically correct ones (Spear-Swerling, 2018). These rules encompass the sequence and function of words, as well as the necessary punctuation for comprehensible written language (Ray, 2020). As a component of grammar, syntax in Tamil education should prioritize functional grammar over traditional structural mastery, emphasizing meaning and usage rather than strict form. This approach can help mitigate learning difficulties (Shakunthala, 2017). Understanding Tamil grammar involves knowledge of verb forms, agreement inflection, argument structure (including case relations), and associated auxiliary elements expressing tense, aspects, attitudes, reflexivity, voice, moods, negations, embedding, etc. (Sarma, 2014).

Tamil-speaking children may exhibit a broader acceptance of various relational structures that can be associated with a verb. However, their comprehension appears more explicit when an argument is expressed, particularly with verbs accompanied by overtly expressed arguments, unlike bare verbs. The learning task for Tamil-speaking children differs fundamentally from that of English-speaking children due to the distinct linguistic contexts in

which adults use verbs, potentially directing attention to different aspects of a scene (Sethuraman et al., 2011).

Tamil verbs can serve as either major or auxiliary, existing in finite and non-finite forms similar to English. Notably, Tamil finite verbs convey more grammatical information compared to their English counterparts, marking features such as number, person, gender, case, tense, mood, etc. (Thangarasu & Inbarani, 2016). The fundamental word order in Tamil is Subject-Object-Verb (S-O-V), offering a pragmatically neutral interpretation. However, due to the scrambling of phrases to the left and right of the verb, alternative surface orders like Object-Subject-Verb (O-S-V), Subject-Verb-Object (S-V-O), and Object-Verb-Subject (O-V-S) are also feasible (Lakshmanan, 2021).

The instruction of syntactic structures plays a crucial role in enhancing children's reading comprehension. The impact of syntax on reading comprehension is particularly pronounced when oral vocabulary levels are low (Rodríguez-Ortiz et al., 2021). Children possessing adequate syntactic awareness demonstrate greater competence in elaborating written narratives, showcasing proficiency in orthographic aspects and the development of textual coherence (Soares et al., 2020). Syntactic knowledge contributes indirectly to reading comprehension through activities such as inference making, comprehension monitoring, and word reading (Zhao et al., 2021). In Grade 3, syntactic awareness serves as a predictor for gains in reading comprehension between Grades 3 and 4 (Deacon & Kieffer, 2018). Additionally, both syntactic awareness and morphological awareness are skills that show a correlation with reading comprehension (Simpson et al., 2019).

Understanding syntax enhances reading and significantly affects reading comprehension. The utilization of visual-syntactic text formatting, coupled with targeted guidance on aligning such formatting with sentence structures, has been identified as an effective approach to enhance reading comprehension (Gao et al., 2021). the capacity to chunk information shows an increase in narrative parameters, and this tendency grows with age, indicating a gradual improvement in the observed performance of narrative tasks (Venkatraman & Thiruvalluvan, 2021), syntactic awareness correlate with reading comprehension, and it was confirmed that syntactic awareness affects reading comprehension (Cho & Kim, 2019), furthermore, it is worth noting that syntactic awareness exhibited the most robust correlation with reading comprehension (Shen & Park's, 2018).

Semantic Development

The term semantics denotes both a specific component of language and the linguistic discipline that studies this component. Semantics also deals with questions such as the nature of linguistic meaning, the semantic properties of linguistic units, and the types of relations between those units. Semantics is conceptualized as a structured set of rules linking a representation of meaning to a representation of the sentence, as per Mel'Čuk et al. (2020). The exploration and elaboration of meanings for topical nouns or verbs can be achieved through semantic feature mapping, with semantic features representing specific component meanings associated with words (Haynes et al., 2019). The pre-existing semantic associations occur in the brain during the learning reading process (Healey & Uitvlugt, 2019). The distinction between good and poor comprehenders extends beyond differences in lexical semantic knowledge to encompass variations in lexical-semantic processing (Bender de Sousa et al., 2020). Word reading can be achieved through graphic-phonological processing and lexico-semantic processing (Mathur et al., 2020).

Tamil classical literature is rich in figurative and literal meanings that convey moral, philosophical, and ethical principles. Tamil verbs exhibit a predictable and unpredictable expansion of their range of meanings or usage, as highlighted by Sankaravelayuthan (2021). Notably, verbs are fewer in number than nouns in Tamil, yet they are more polysemous. The meanings of verbs can vary depending on the types of noun arguments with which they co-occur, while the meanings of nouns tend to be more stable across different verbs (Rajendran, 2006).

In Tamil, numerous nouns can be considered as the epicene form, devoid of gender markings, of gender-marked nouns (Sankaralingam et al., 2017). The vocabulary of Tamil is initially categorized into four domains: entities, which encompass referential meanings of concrete concepts; events, primarily composed of verbs; abstracts, consisting predominantly of adjectives and adverbs in addition to abstract nouns; and relations, comprising functional words such as postpositions, connectives, and coordinators. Examining verbs in terms of semantic relations can offer insights into understanding their syntactic behavior (Rajendran et al., 2020).

The inclusion of semantically transparent radicals has been found to enhance children's

orthographic recognition. The amalgamation of semantic information with phonological and orthographic details contributes to an improved recognition of words. In tasks requiring recognition, children tend to depend more on meaningful information rather than solely on phonological cues (Li et al., 2019). Understanding both the meaning and phonological form of words not only aids in the formation of orthographic representations but also enhances children's overall reading performance (Álvarez-Cañizo et al., 2018).

The teaching intervention focused on word reading and learning complex abstracts to increase reading fluency and develop semantic knowledge. The development of verb vocabulary is influenced by both the syntactic and semantic properties of verbs, and this influence shows variation based on age and language ability (Horvath et al., 2021). Transparent semantic radicals have been observed to ease the process of orthographic and vocabulary learning (Li et al., 2021). In interventions, improvements in children's word-finding abilities were noted, with statistically significant changes occurring specifically during treatment phases and not during baseline periods (Best et al., 2021). Furthermore, the positive impact of semantic knowledge extends to working memory recognition performance (Artuso et al., 2019).

The early comprehension, production, and learning of language are influenced by lexical–semantic relations (Wojcik, 2017). The initial processing and learning of novel words are distinctly shaped by orthographic, semantic, and contextual factors (Yi et al., 2022). Semantic learning is a direct predictor of reading comprehension (Mimeau et al., 2018). For all children, phonological awareness and semantic knowledge emerge as robust predictors of reading development (Jasińska & Petitto, 2017). Additionally, word semantic knowledge has a positive impact on content inference, receptive vocabulary, word recognition, and the attainment of reading mastery goals (Dong et al., 2020).

Reading Comprehension

Reading comprehension is not only essential for understanding specific texts but also plays a crucial role in broader learning and education (Oakhill et al., 2019). It encompasses the transformation of written text into thoughts or meaning, constituting a simultaneous extraction and construction of meaning through interaction with the text (Kong, 2019). A complex process, reading comprehension involves a range of cognitive and linguistic skills (Nation, 2019). It stems from the development of decoding and understanding the written

form of a language, with the progress in reading development significantly influenced by the typological and orthographical features of a language (Nesan et al., 2019). Understanding written passages requires the development of language comprehension abilities, which are particularly important in the written modality (Caplan et al., 2016).

The primary determinants of reading comprehension in children are background knowledge and their decoding abilities. To enhance comprehension skills, it is essential to place early and sustained emphasis on developing background knowledge, expanding vocabulary, fostering inference abilities, and honing comprehension monitoring skills throughout the developmental process (Elleman & Oslund, 2019), background knowledge impacts differentially on stronger and weaker readers (Smith et al., 2021), the significance of background knowledge, vocabulary, word reading, strategies, and inferencing on comprehension is evident through both direct and indirect effects, maintaining significance across various grade levels and treatment conditions (Ahmed et al., 2021).

Scientific research has identified numerous individual and combined instructional strategies that contribute to the development of reading comprehension. Accurate reading of words is emphasized because it forms a foundation for building an accurate understanding of the text (Duke et al., 2021). Instructional practices that involve modeling, guided practice opportunities, and corrective feedback have demonstrated significant impacts on improving reading comprehension performance (Joseph et al., 2021). Reading fluency, reading accuracy, and oral comprehension skills have a direct influence on reading comprehension (Angelelli et al., 2021). Cognitive flexibility interventions that integrate graphophonological and semantic aspects impact reading comprehension (Cartwright et al., 2020). Early morphological and vocabulary knowledge directly predict reading comprehension in children (Verhoeven et al., 2019). Additionally, word reading and receptive vocabulary stand out as significant and unique predictors of English reading comprehension (Al Janaideh et al., 2020).

Comprehension is also improved by teaching intervention through questioning, sequencing, and drawing inferences. Inference-making becomes increasingly crucial as a child grows, significantly impacting language and social development (Aishwarya & Deborah, 2020). Metacognitive and inferential skills, particularly effective in fostering both improved comprehension and meta-comprehension, play a vital role in cognitive development (Soto et

al., 2019). Sequencing is identified as a pivotal skill for comprehending narrative texts (Gouldthorp et al., 2017). Asking questions has been found to enhance critical thinking and contribute to the growth of reading comprehension in elementary students (Hale & Kim, 2020).

Various strategies, including the use of graphic organizers, questioning, story mapping, peer-assisted strategies, think aloud, discussing the text with students, and employing different grouping methods, have been shown to improve reading comprehension (Almutairi, 2018). Contextual Teaching and Learning have been associated with increased student motivation and improved reading comprehension (Haerazi et al., 2019). Additionally, students undergoing specific treatments maintained higher levels of reading comprehension (Wanzek et al., 2019). Implementing evidence-based literacy instruction across various content areas has proven to be an effective approach for improving reading comprehension (Gutierrez de Blume et al., 2020). The interplay between language and knowledge can synergistically impact linguistic comprehension, ultimately contributing to improved reading comprehension (Cabell & Hwang, 2020). Furthermore, individuals struggling with comprehension can successfully engage with challenging texts when accompanied by appropriate instructional support (Lupo et al., 2019).

Conclusion and Limitations

In conclusion, the attainment of successful reading fluency is intricately tied to linguistic and decoding abilities, with later reading fluency being shaped by the trajectory of these foundational skills. Our findings highlight the pivotal role of phonological awareness development, which enables children to discern various sound patterns, ultimately connecting them to written symbols. Once this milestone is achieved, children embark on a journey of word spelling proficiency. Additionally, the cultivation of word morphology understanding equips them with the knowledge of word origins and formation. Furthermore, our research underscores the importance of syntactic knowledge in constructing coherent sentences and comprehending the grammatical nuances of language. This linguistic competence is further complemented by semantic knowledge, which enables children to grasp the meanings of words within the context of a sentence. Moreover, we emphasize the significance of comprehension exercises and activities that leverage background knowledge to enhance reading comprehension skills. These practices serve as valuable tools for improving overall

reading proficiency.

Based on these findings, it is clear that a teaching intervention grounded in the SRM framework holds promise for enhancing the reading fluency of Tamil children, irrespective of whether they face initial reading difficulties. This framework provides a structured and effective approach to nurturing the essential skills that underpin fluent reading, paving the way for improved literacy outcomes.

Based on our extensive review, we recommend the adoption of a teaching intervention grounded in the Smart Reading Module (SRM) for Tamil children facing reading challenges. While our review predominantly revolves around SRM-based strategies, it's crucial to underscore our primary focus on specific reading skills harmonized with the Tamil language. Moreover, our analysis primarily focuses on skills development that aligns with the Simple View of Reading (SVR) theory.

It's imperative to recognize that our review has deliberately focused on specific reading components supported by empirical research within the context of Tamil reading development, primarily emphasizing SVR-based decoding and linguistic growth. We strongly encourage future investigations to encompass a broader spectrum of reading development components, potentially offering invaluable support to Tamil children grappling with reading difficulties. In essence, our recommendation centers on the implementation of SRM-based teaching interventions thoughtfully tailored to meet the unique needs of Tamil children experiencing reading challenges. We acknowledge the untapped potential of exploring a wider array of reading development facets, which could significantly contribute to enhancing the reading proficiency of these children in the future.

The insights derived from this scoping review carry profound significance, serving as an invaluable resource for a diverse range of stakeholders. Educators, researchers, policymakers, and all individuals deeply invested in elevating the reading competence of Tamil readers will find this compilation of findings an indispensable guide and reference point.

Implications and Future Research

This study, offering a comprehensive review of Tamil reading development, illuminates both

its present implications and future research avenues. This underscores the dynamic nature of the field, emphasizing the need for continuous exploration and innovation to bolster Tamil children's reading skills. The study delves into the challenges faced by Tamil-speaking children and proposes a Smart Reading Module-based teaching intervention, enriching the field of reading development for Tamil children with difficulties.

Educators, especially in Tamil-speaking regions, can extract valuable insights from this research, emphasizing the importance of tailored instruction in Tamil. Integrating the SRM-based model into their teaching practices can enhance reading fluency for struggling students. Policymakers in Tamil-speaking areas can draw from this study to craft language-specific reading policies and curriculum frameworks that align with Tamil's unique linguistic characteristics.

Furthermore, this research underscores the significance of preserving and promoting the Tamil language in education. By aligning reading frameworks with its distinctive features, it contributes to safeguarding Tamil as a rich and distinct linguistic heritage. The proposed Smart Reading Module-based teaching intervention model can be explored and implemented in schools, particularly for children encountering reading challenges in Tamil. It offers a practical, research-backed approach to tackle these issues effectively.

Future research should delve into comparative studies between Tamil and languages with complex orthographic systems, revealing insights to shape effective interventions. Multilingual regions like Tamil Nadu should be studied to understand how multilingualism influences reading development, necessitating tailored interventions. Longitudinal studies can trace the long-term impact of SRM interventions, from early childhood to adolescence, enhancing comprehension and fluency.

The influence of cultural and socioeconomic factors on Tamil-speaking children's reading proficiency requires investigation, enriching our understanding. Leveraging technology, research can explore digital tools and resources that align with Tamil's unique characteristics, improving reading development. Rigorous assessments via large-scale empirical studies are needed to validate the Smart Reading Module-based teaching intervention's efficacy in enhancing reading fluency and comprehension.

Finally, research should explore the adaptability of this model to languages with similar linguistic features, broadening its impact. This article lays the foundation for further research, emphasizing the importance of language-specific approaches and fostering continued innovation in supporting Tamil-speaking children's reading skills, particularly those facing difficulties.

References

Ahmed, Y., Miciak, J., Taylor, W. P., & Francis, D. J. (2021). Structure Altering Effects of a Multicomponent Reading Intervention: An Application of the Direct and Inferential Mediation (DIME) Model of Reading Comprehension in Upper Elementary Grades. *Journal of Learning Disabilities*, https://doi.org/10.1177/0022219421995904

Aishwarya, N., & Deborah, D. R. (2020). Comparison of Narrative Comprehension and Inference-Making ability in Native Tamil speakers in monolingual and bilingual contexts. *Journal of Research in Childhood Education*, *35*(4), 616–630. https://doi.org/10.1080/02568543.2020.1810181

Al Janaideh, R., Gottardo, A., Tibi, S., Paradis, J., & Chen, X. (2020). The role of word reading and oral language skills in reading comprehension in Syrian refugee children. *Applied Psycholinguistics*, 41(6), 1283–1304. https://doi.org/10.1017/s0142716420000284

Almutairi, N. R. (2018). Effective Reading Strategies for Increasing the Reading Comprehension Level of Third-Grade Students with Learning Disabilities. *Dissertation*. https://scholarworks.wmich.edu/dissertations/3247

Álvarez-Cañizo, M., Suárez-Coalla, P., & Cuetos, F. (2018). Orthographic learning in Spanish children: influence of previous semantic and phonological knowledge. *Journal of Research in Reading*, *42*(1), 137–149. https://doi.org/10.1111/1467-9817.12254

Amirjalili, F., & Jabbari, A. A. (2018). The impact of morphological instruction on morphological awareness and reading comprehension of EFL learners. *Cogent Education*, *5*(1). https://doi.org/10.1080/2331186x.2018.1523975

Anderson, K., & Scanlon, D. (2020). The Development of Sight Vocabulary. *The Reading Teacher*, *74*(3), 346–352. https://doi.org/10.1002/trtr.1953

Angelelli, P., Romano, D. L., Marinelli, C. V., Macchitella, L., & Zoccolotti, P. (2021). The Simple View of Reading in Children Acquiring a Regular Orthography (Italian): A

Network Analysis Approach. *Frontiers in Psychology*, *12*. https://doi.org/10.3389/fpsyg.2021.686914

Artuso, C., Palladino, P., & Belacchi, C. (2019). Sensitivity detection in memory recognition: interference control as index of taxonomic memory development? *Memory*, *28*(2), 187–195. https://doi.org/10.1080/09658211.2019.1705488

Bart-Addison, S., & Griffin, R. A. (2021). A Structured Literacy Approach to Support Striving Readers in Secondary Grades: Meaningful Transactions through Morphological Awareness and Fluency Building. *Georgia Journal of Literacy*, Vol. 44: No. 1.

Bender de Sousa, L., Hübner, L. C., & Ferreira da Silva, R. B. (2020). Lexical-semantic integration by good and poor reading comprehenders. *Ilha Do Desterro a Journal of English Language, Literatures in English and Cultural Studies*,

Best, W., Hughes, L., Masterson, J., Thomas, M. S. C., Howard, D., Kapikian, A., & Shobbrook, K. (2021). Understanding differing outcomes from semantic and phonological interventions with children with word-finding difficulties: A group and case series study. *Cortex*, *134*, 145–161. https://doi.org/10.1016/j.cortex.2020.09.030

Bhuvaneshwari, B., & Padakannaya, P. (2013). *Reading in Tamil: a more alphabetic and less syllabic akshara-based orthography*. In Cambridge University Press eBooks (pp. 192–201). https://doi.org/10.1017/cbo9781139084642.022

Bishara, S. (2020). Association between Phonological and Morphological Awareness and Reading Comprehension among Special-Education Children in Arab Elementary Schools. *International Journal of Disability, Development, and Education*, 1–18. https://doi.org/10.1080/1034912x.2020.1737319

Breadmore, H.L., Vardy, E.J., Cunningham, A.J., Kwok, R.K.W., & Carroll, J.M. (2019). *Literacy Development: Evidence Review*. London: Education Endowment Foundation. The report is available from:https://educationendowmentfoundation.org.uk/public/files/Literacy_Development_Evidence_Review.pdf

Britt, M. A., Rouet, J., Durik, A., & Jean-François Rouet. (2018). *Literacy Beyond Text Comprehension*. Routledge. New York.

Cabell, S. Q., & Hwang, H. (2020). Building Content Knowledge to Boost Comprehension in the Primary Grades. *Reading Research Quarterly*, *55*(S1). https://doi.org/10.1002/rrq.338

Campen, C. K., Segers, E., & Verhoeven, L. (2018). How phonological awareness mediates

the relation between working memory and word reading efficiency in children with dyslexia. *Dyslexia*, *24*(2), 156–169. https://doi.org/10.1002/dys.1583

Caplan, D., Waters, G., Bertram, J., Ostrowski, A., & Michaud, J. (2016). Effects of Written and Auditory Language-Processing Skills on written passage comprehension in middle and high school students. *Reading Research Quarterly*, *51*(1), 67–92. https://doi.org/10.1002/rrq.126

Cárnio, M. S., Vosgrau, J. S., & Soares, A. J. C. (2017). The role of phonological awareness in reading comprehension. *Revista CEFAC*, *19*(5), 590–600. https://doi.org/10.1590/1982-0216201619518316

Cartwright, K. B., Bock, A. M., Clause, J. H., Coppage August, E. A., Saunders, H. G., & Schmidt, K. J. (2020). Near- and far-transfer effects of an executive function intervention for 2nd to 5th-grade struggling readers. *Cognitive Development*, *56*, 100932. https://doi.org/10.1016/j.cogdev.2020.100932

Castles, A., Rastle, K., & Nation, K. (2018). Ending the Reading Wars: Reading Acquisition from Novice to expert. *Psychological Science in the Public Interest*, *19*(1), 5–51. https://doi.org/10.1177/1529100618772271

Cho, M.-K., & Kim, M. (2019). A Study of the Correlation between Syntactic Awareness Characteristics and Reading Comprehension for School-aged Children with Language-Learning Disabilities in Grades 3-4. *Communication Sciences & Disorders*, 24(1), 31–46. https://doi.org/10.12963/csd.19576

Cunningham, A., Burgess, A., Witton, C., Talcott, J. B., & Shapiro, L. R. (2021). Dynamic relationships between phonological memory and reading: A five-year longitudinal study from age 4 to 9. *Developmental Science*, *24*(1). https://doi.org/10.1111/desc.12986

Deacon, S. H., & Kieffer, M. (2018). Understanding how syntactic awareness contributes to reading comprehension: Evidence from mediation and longitudinal models. *Journal of Educational Psychology*, *110*(1), 72–86. https://doi.org/10.1037/edu0000198

Deacon, S. H., Tong, X., & Mimeau, C. (2019). Morphological and Semantic Processing in Developmental Dyslexia. *Developmental Dyslexia across Languages and Writing Systems*, 327–349. https://doi.org/10.1017/9781108553377.015

Diamanti, V., Mouzaki, A., Ralli, A. M., Antoniou, F., Papaioannou, S., & Protopapas, A. (2017). Preschool Phonological and Morphological Awareness as Longitudinal Predictors of Early Reading and Spelling Development in Greek. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.02039

Dong, Y., Chow, B. W.Y., Wu, S. X., Zhou, J.D., & Zhao, Y. M. (2020). Enhancing Poor Readers' Reading Comprehension Ability through Word Semantic Knowledge Training. *Reading & Writing Quarterly*, 1–17. https://doi.org/10.1080/10573569.2020.1820410

Duke, N. K., Ward, A. E., & Pearson, P. D. (2021). The Science of Reading Comprehension Instruction. *The Reading Teacher*, *74*(6), 663–672. https://doi.org/10.1002/trtr.1993

Ehri, L. C. (2020). The Science of Learning to Read Words: A Case for Systematic Phonics Instruction. *Reading Research Quarterly*, *55*(S1). https://doi.org/10.1002/rrq.334

Elleman, A. M., & Oslund, E. L. (2019). Reading Comprehension Research: Implications for Practice and Policy. *Policy Insights from the Behavioral and Brain Sciences*, *6*(1), 3–11. https://doi.org/10.1177/2372732218816339

Enderby, J. L., Carroll, J. M., Tarczynski-Bowles, M. L., & Breadmore, H. L. (2021). The roles of morphology, phonology, and prosody in reading and spelling multisyllabic words. *Applied Psycholinguistics*, 1–21. https://doi.org/10.1017/s0142716421000096

Erskine, M. E., Munson, B., & Edwards, J. (2020). Relationship between early phonological processing and later phonological awareness: Evidence from nonword repetition. *Applied Psycholinguistics*, *41*(2), 319–346. https://doi.org/10.1017/s0142716419000547

Flynn, N., Powell, D., Stainthorp, R., & Stuart, M. (2021). Training teachers for phonics and early reading: Developing research-informed practice. *Journal of Research in Reading*, *44*(2). https://doi.org/10.1111/1467-9817.12336

Gallet, C., Viriot-Goeldel, C., & Leclercq, V. (2020). Effects of an early reading intervention based on grapho-syllabic decoding and fluency training in French elementary schools. European *Review of Applied Psychology*, 70(1), 100471. https://doi.org/10.1016/j.erap.2019.100471

Galuschka, K., Görgen, R., Kalmar, J., Haberstroh, S., Schmalz, X., & Schulte-Körne, G. (2020). Effectiveness of spelling interventions for learners with dyslexia: A meta-analysis and systematic review. *Educational Psychologist*, 55(1), 1–20. https://doi.org/10.1080/00461520.2019.1659794

Gangl, M., Moll, K., Banfi, C., Huber, S., Schulte-Körne, G., & Landerl, K. (2018). Reading strategies of good and poor readers of German with different spelling abilities. *Journal of Experimental Child Psychology*, *174*, 150–169. https://doi.org/10.1016/j.jecp.2018.05.012

Gao, W., Namaziandost, E., & Abdulaal, M. A. A.-D. (2021). Visual-Syntactic Text

Formatting: Developing EFL Learners' Reading Fluency Components. *Journal of Psycholinguistic Research*. https://doi.org/10.1007/s10936-021-09823-x

Garcia, R. B., Tomaino, A., & Cornoldi, C. (2019). Cross-modal working memory binding and learning of visual-phonological associations in children with reading difficulties. *Child Neuropsychology*, 25(8), 1063–1083. https://doi.org/10.1080/09297049.2019.1572729

Georgiou, G. K., Savage, R., Dunn, K., Bowers, P., & Parrila, R. (2020). Examining the effects of Structured Word Inquiry on the reading and spelling skills of persistently poor Grade 3 readers. *Journal of Research in Reading*. https://doi.org/10.1111/1467-9817.12325

Georgiou, G. K., Torppa, M., Landerl, K., Desrochers, A., Manolitsis, G., de Jong, P. F., & Parrila, R. (2019). Reading and Spelling Development Across Languages Varying in Orthographic Consistency: Do Their Paths Cross? *Child Development*, *91*(2). https://doi.org/10.1111/cdev.13218

Ginestet, E., Shadbolt, J., Tucker, R., Bosse, M., & Deacon, S. H. (2020). Orthographic learning and transfer of complex words: insights from eye tracking during reading and learning tasks. *Journal of Research in Reading*, *44*(1), 51–69. https://doi.org/10.1111/1467-9817.12341

Goodwin, A. P., Petscher, Y., & Tock, J. L. (2021). Multidimensional morphological assessment for middle school students. *Journal of Research in Reading*, *44*(1), 70–89. https://doi.org/10.1111/1467-9817.12335

Görgen, R., De Simone, E., Schulte-Körne, G., & Moll, K. (2021). Predictors of reading and spelling skills in German: the role of morphological awareness. *Journal of Research in Reading*, *44*(1), 210–227. https://doi.org/10.1111/1467-9817.12343

Gouldthorp, B., Katsipis, L., & Mueller, C. (2017). An Investigation of the Role of Sequencing in Children's Reading Comprehension. *Reading Research Quarterly*, *53*(1), 91–106. https://doi.org/10.1002/rrq.186

Gutierrez De Blume, A. P., Katz, A., & Bass, J. (2020). Impact of literacy across content on middle school students' reading comprehension in a rural context. *Journal of Research in Reading*, 44(2), 284–300. https://doi.org/10.1111/1467-9817.12334

Haase, A., & Steinbrink, C. (2022). Associations between morphological awareness and literacy skills in German primary school children: the roles of grade level, phonological processing, and vocabulary. *Reading and Writing*. https://doi.org/10.1007/s11145-021-10247-1

Haerazi, H., Prayati, Z., & Vikasari, R. M. (2019). Practicing Contextual Teaching and Learning (CTL) Approach to Improve Students. Reading Comprehension In Relation To Motivation. *English Review: Journal of English Education*, *8*(1), 139. https://doi.org/10.25134/erjee.v8i1.2011

Hale, E., & Kim, J. S. (2020). Providing Platforms. *The Elementary School Journal*, 120(4), 555–579. https://doi.org/10.1086/708665

Haynes, C. W., Smith, S. L., & Laud, L. (2019). Structured Literacy Approaches to Teaching Written Expression. *Perspectives on Language and Literacy*, 22–28. https://www.DyslexiaIDA.org

Healey, M. K., & Uitvlugt, M. G. (2019). The role of control processes in temporal and semantic contiguity. *Memory & Cognition*. https://doi.org/10.3758/s13421-019-00895-8

Henbest, V. S., & Apel, K. (2017). Effective word reading instruction: What does the evidence tell us? *Communication Disorders Quarterly*, 39(1), 303–311. https://doi.org/10.1177/1525740116685183

Ho, C. S., Zheng, M., McBride, C., Hsu, L. S. J., Waye, M. M. Y., & Kwok, J. C. (2017). Examining an extended simple view of reading in Chinese: The role of naming efficiency for reading comprehension. *Contemporary Educational Psychology*, *51*, 293–302. https://doi.org/10.1016/j.cedpsych.2017.08.009

Hodgins, H., & Harrison, G. L. (2021). Improving phonological awareness with Talking Tables in at-risk kindergarten readers. *Research in Developmental Disabilities*, *115*, 103996. https://doi.org/10.1016/j.ridd.2021.103996

Hoover, W. A., & Gough, P. B. (1990). The simple view of reading. *Reading and Writing*, *2*(2), 127–160. https://doi.org/10.1007/bf00401799

Hoover, W. A., & Tunmer, W. E. (2018). The Simple View of Reading: Three Assessments of Its Adequacy. *Remedial and Special Education*, *39*(5), 304–312. https://doi.org/10.1177/0741932518773154

Horbach, J., Weber, K., Opolony, F., Scharke, W., Radach, R., Heim, S., & Günther, T. (2018). Performance in Sound-Symbol Learning Predicts Reading Performance 3 Years Later. *Frontiers in Psychology*, *9*. https://doi.org/10.3389/fpsyg.2018.01716

Horvath, S., Kueser, J. B., Kelly, J., & Borovsky, A. (2021). Difference or Delay? Syntax, Semantics, and Verb Vocabulary Development in Typically Developing and Late-talking Toddlers. *Language Learning and Development*, 1–25. https://doi.org/10.1080/15475441.2021.1977645

Hung, Y. H., Frost, S.J., & Pugh, K.R. (2018). *Domain Generality and Specificity of Statistical Learning and its Relation with Reading Ability*. In: Lachmann, T., Weis, T. (eds) Reading, and Dyslexia. Literacy Studies, vol. 16. Springer, Cham. https://doi.org/10.1007/978-3-319-90805-2_2

International Dyslexia Association (2019). Structured Literacy: An Introductory Guide. www.DyslexiaIDA.org

International Literacy Association. (2019). Children experiencing reading difficulties: What we know and what we can do [Literacy leadership brief]. Newark, DE.

Jasińska, K. K., & Petitto, L.-A. (2017). Age of Bilingual Exposure Is Related to the Contribution of Phonological and Semantic Knowledge to Successful Reading Development. *Child Development*, 89(1), 310–331. https://doi.org/10.1111/cdev.12745

Joseph, L., Ross, K., Xia, Q., Amspaugh, L. A., & Accurso, J. (2021). Reading Comprehension Instruction for Students with Intellectual Disabilities: A Systematic Literature Review. *International Journal of Disability, Development, and Education*, 1–26. https://doi.org/10.1080/1034912x.2021.1892033

Joshi, R. M., & McBride, C. (Eds.). (2019). *Handbook of Literacy in Akshara Orthography*. Literacy Studies. https://doi.org/10.1007/978-3-030-05977-4

Kanapathy, K. (2019). Phonological game-based module to enhance Tamil school Linus program. *Religación. Revista De Ciencias Sociales Y Humanidades*, 4(15), 50–56.

Karpagavalli, S., Viji Gripsy, J., & Nandhini, K. (2021). Speech assistive Tamil learning mobile applications for learning disability children. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2021.01.050

Kelly, C., Leitão, S., Smith-Lock, K., & Heritage, B. (2017). The effectiveness of a classroom-based phonological awareness program for 4–5-year-olds. *International Journal of Speech-Language Pathology*, *21*(1), 101–113. https://doi.org/10.1080/17549507.2017.1400589

Kelso, K., Whitworth, A., Parsons, R., & Leitão, S. (2020). Hidden Reading Difficulties: Identifying Children Who Are Poor Comprehenders. *Learning Disability Quarterly*, 073194872096176. https://doi.org/10.1177/0731948720961766

Khateb, A., & Bar-Kochva, I. (2018). *Reading Fluency: Current Insights from Neurocognitive Research and Intervention Studies (Literacy Studies, 12).* Springer. Switzerland.

Kjeldsen, A., Educ, L., Saarento-Zaprudin, S. K., & Niemi, P. (2019). Kindergarten Training

in Phonological Awareness: Fluency and Comprehension Gains Are Greatest for Readers at Risk in Grades 1 Through 9. *Journal of Learning Disabilities*, *52*(5), 366–382. https://doi.org/10.1177/0022219419847154

Kong, J. (2019). Theories of Reading Comprehension. *Investigating the Role of Test Methods in Testing Reading Comprehension*, 9–29. https://doi.org/10.1007/978-981-13-7021-2_2

Krishnamurthy, P., & Sarveswaran, K. (2021). Towards Building a Modern Written Tamil Treebank. *In Proceedings of the 20th International Workshop on Treebanks and Linguistic Theories (TLT, SyntaxFest 2021)*, pages 61–68, Sofia, Bulgaria. Association for Computational Linguistics.

Lakshmanan, L. (2021). The Acquisition of Recursive Possessives in Child Tamil. *Proceedings of the 45th annual Boston University Conference on Language Development*, ed. Danielle Dionne and Lee-Ann Vidal Covas, 462-470.

Law, J. M., De Vos, A., Vanderauwera, J., Wouters, J., Ghesquière, P., & Vandermosten, M. (2018). Grapheme-Phoneme Learning in an Unknown Orthography: A Study in Typical Reading and Dyslexic Children. *Frontiers in Psychology*, *9*. https://doi.org/10.3389/fpsyg.2018.01393

Layes, S., Guendouz, M., Lalonde, R., & Rebai, M. (2020). Combined Phonological Awareness and Print Knowledge Training Improves Reading Accuracy and Comprehension in Children with Reading Disabilities. *International Journal of Disability Development and Education*, *69*(4), 1185–1199. https://doi.org/10.1080/1034912x.2020.1779914

Levesque, K. C., Breadmore, H. L., & Deacon, S. H. (2020). How morphology impacts reading and spelling: advancing the role of morphology in models of literacy development. *Journal of Research in Reading*, *44*(1), 10–26. https://doi.org/10.1111/1467-9817.12313

Li, Y., Li, H., & Wang, M. (2019). The Roles of Phonological Recoding, Semantic Radicals and Writing Practice in Orthographic Learning in Chinese. *Scientific Studies of Reading*, *24*(3), 252–263. https://doi.org/10.1080/10888438.2019.1663199

Li, Y., Xiao, L., & Li, H. (2021). Self-teaching in Chinese: the roles of phonetic and semantic radicals in orthographic and vocabulary learning. *Journal of Research in Reading*, *45*(1), 20–42. https://doi.org/10.1111/1467-9817.12379

Lidz, J., & Perkins, L. (2018). Language Acquisition. *Stevens' Handbook of Experimental Psychology and Cognitive Neuroscience*, 1–49.

https://doi.org/10.1002/9781119170174.epcn403

Liu, C., Chung, K. K. H., Wang, L., & Liu, D. (2020). The relationship between paired associate learning and Chinese word reading in kindergarten children. *Journal of Research in Reading*, 44(2), 264–283. https://doi.org/10.1111/1467-9817.12333

Lundetræ, K., & Thomson, M. J. (2017). *Rhythm production at school entry as a predictor of poor reading and spelling at the end of first grade.* SpringerLink. https://link.springer.com/article/10.1007/s11145-017-9782-9

Lunte, T., & Boll, S. (2020). Towards a gaze-contingent reading assistance for children with difficulties in reading. *The 22nd International ACM SIGACCESS Conference on Computers and Accessibility*. https://doi.org/10.1145/3373625.3418014

Lupo, S. M., Tortorelli, L., Invernizzi, M., Ryoo, J.H., & Strong, J. Z. (2019). An exploration of text difficulty and knowledge support on adolescents' comprehension. *Reading Research Quarterly*, *54*(4), 457–479. https://doi.org/10.1002/rrq.247

Lyster, S. H., Snowling, M. J., Hulme, C., & Lervåg, A. (2021). Preschool phonological, morphological, and semantic skills explain it all: following reading development through a 9-year period. *Journal of Research in Reading*, *44*(1), 175–188. https://doi.org/10.1111/1467-9817.12312

Mather, N., & Jaffe, L. (2021). Orthographic Knowledge Is Essential for Reading and Spelling. The Reading League Journal, 2(3), 15–24.

Mathur, A., Schultz, D., & Wang, Y. (2020). Neural bases of phonological and semantic processing in early childhood. *Brain Connectivity*. https://doi.org/10.1089/brain.2019.0728

Mathur, C., & Nag, S. (2019). Language-Focused instruction for Literacy acquisition in Akshara-based Languages: Pedagogical Considerations and challenges. In *Literacy studies* (pp. 279–309). https://doi.org/10.1007/978-3-030-05977-4_15

Matusky, R. (2018). *Needs Assessment vs. Needs Analysis — What's the Difference? Medium*. Retrieved from: https://medium.com/@Randy_Matusky/needs-assessment-vs-needs-analysis-whats-the-difference-54a9eef0b44c

McArthur, G., Sheehan, Y., Badcock, N. A., Francis, D. A., Wang, H.-C., Kohnen, S., Banales, E., Anandakumar, T., Marinus, E., & Castles, A. (2018). Phonics training for English-speaking poor readers. *Cochrane Database of Systematic Reviews*. https://doi.org/10.1002/14651858.cd009115.pub3

Mel'Čuk, I., Milićević, J., & Mel'čuk, I. (2020). *An Advanced Introduction to Semantics*: *a meaning-text approach* Cambridge University Press. UK.

Miles, K.P., Ehri, L.C. (2019). *Orthographic Mapping Facilitates Sight Word Memory and Vocabulary Learning*. In: Kilpatrick, D., Joshi, R., Wagner, R. (eds) Reading Development and Difficulties. 63-82. Springer, Cham. https://doi.org/10.1007/978-3-030-26550-2_4

Milledge, S. V., Zang, C., Liversedge, S. P., & Blythe, H. I. (2022). Phonological parafoveal pre-processing in children reading English sentences. *Cognition*, *225*, 105141. https://doi.org/10.1016/j.cognition.2022.105141

Mimeau, C., Ricketts, J., & Deacon, S. H. (2018). The Role of Orthographic and Semantic Learning in Word Reading and Reading Comprehension. *Scientific Studies of Reading*, *22*(5), 384–400. https://doi.org/10.1080/10888438.2018.1464575

Moats, L. (2019). Structured Literacy: Effective Instruction for Students with Dyslexia and Related Reading Difficulties. *Perspectives on Language and Literacy*, 9–11. https://www.DyslexiaIDA.org

Moats, L. C. (2020). *Teaching reading is rocket science: What expert teachers of reading should know and be able to do.* Washington, DC: American Federation of Teachers.

Moher, D., Shamseer, L., Clarke, M. *et al.* Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst Rev* **4**, 1 (2015). https://doi.org/10.1186/2046-4053-4-1

Müller, B., Richter, T., & Karageorgos, P. (2020). Syllable-based reading improvement: Effects on word reading and reading comprehension in Grade 2. *Learning and Instruction*, *66*, 101304. https://doi.org/10.1016/j.learninstruc.2020.101304

Nag, S., & Narayanan, B. (2019). Orthographic Knowledge, Reading and Spelling Development in Tamil: the first three years. In *Literacy studies* (pp. 55–83). https://doi.org/10.1007/978-3-030-05977-4_4

Nation, K. (2019). Children's reading difficulties, language, and reflections on the simple view of reading. *Australian Journal of Learning Difficulties*, 24(1), 47–73. https://doi.org/10.1080/19404158.2019.1609272

National Reading Panel, (2000). *Report of the National Reading Panel: Teaching Children to Read,* An Evidenced Based Assessment of the Scientific Research Literature on Reading and Its Implications for Reading Instruction (NIH 00-4769).

Nesan, M., Sadeghi, A., & Everatt, J. (2019). Literacy Acquisition in the Malayalam Orthography: Cognitive/Linguistic Influences within a Multilingual Context. In *Literacy studies* (pp. 85–101). https://doi.org/10.1007/978-3-030-05977-4_5

Oakhill, J., Cain, K., & Elbro, C. (2019). Reading Comprehension and Reading

Comprehension Difficulties. *Reading Development and Difficulties*, 83–115. https://doi.org/10.1007/978-3-030-26550-2_5

Paige, D. D., Rupley, W. H., Smith, G. S., Olinger, C., & Leslie, M. (2018). Acquisition of Letter Naming Knowledge, Phonological Awareness, and Spelling Knowledge of Kindergarten Children at Risk for Learning to Read. *Child Development Research, 2018*, 1–10. https://doi.org/10.1155/2018/2142894

Paul, X. & Christopher, G. (2017). Teaching reading skill using heuristic technique through schema theory. *IUP Journal of English Studies*. 12. 11-15.

Petscher, Y., Solari, E. J., & Catts, H. W. (2019). Conditional Longitudinal Relations of Elementary Literacy Skills to High School Reading Comprehension. *Journal of Learning Disabilities*, *52*(4), 324–336. https://doi.org/10.1177/0022219419851757

Pfost, M., Blatter, K., Artelt, C., Stanat, P., & Schneider, W. (2019). Effects of training phonological awareness on children's reading skills. *Journal of Applied Developmental Psychology*, *65*, 101067. https://doi.org/10.1016/j.appdev.2019.101067

Plewko, J., Chyl, K., Bola, Ł., Łuniewska, M., Dębska, A., Banaszkiewicz, A., Wypych, M., Marchewka, A., van Atteveldt, N., & Jednoróg, K. (2018). Letter and Speech Sound Association in Emerging Readers with Familial Risk of Dyslexia. *Frontiers in Human Neuroscience*, *12*. https://doi.org/10.3389/fnhum.2018.00393

Querido, L., Fernandes, S., & Verhaeghe, A. (2021). Orthographic Knowledge, and Reading and Spelling: A Longitudinal Study in an Intermediate Depth Orthography. *The Spanish Journal of Psychology*, *24*. https://doi.org/10.1017/sjp.2021.3

Raghavendra, P., & Leonard, L. B. (1989). The acquisition of agglutinating languages: converging evidence from Tamil. *Journal of Child Language*, 16(2), 313–322. https://doi.org/10.1017/s0305000900010436

Rajendran, S. (2006). *Syntax and Semantics of Verbs of Communication in English and Tamil*. Language in India, 6(2)

Rajendran, S., Soman, K. P., Anandkumar, M., & Sankaralingam, C. (2020). Ontological Structure-Based Retrieval System for Tamil. In *Springer eBooks* (pp. 197–223). https://doi.org/10.1007/978-3-030-35280-6_10

Rekha, R., Kumar, M., Dhanalakshmi, V., Soman, K. P., & Rajendran, S. (2012b). *A novel approach to the morphological generator for Tamil. Lecture Notes in Computer Science*. https://www.amrita.edu/publication/novel-approach-morphological-generator-tamil

Roberts, T. A., Vadasy, P. F., & Sanders, E. A. (2019). Preschoolers' alphabet learning: cognitive, teaching sequence, and English proficiency influences. *Reading Research Quarterly*, *54*(3), 413–437. https://doi.org/10.1002/rrq.242

Rodríguez-Ortiz, I. R., Moreno-Pérez, F. J., Simpson, I. C., Valdés-Coronel, M., & Saldaña, D. (2021). The influence of syntactic knowledge on reading comprehension varies as a function of oral vocabulary in Spanish-speaking children. *Journal of Research in Reading*. https://doi.org/10.1111/1467-9817.12363

Ronimus, M., Eklund, K., Pesu, L., & Lyytinen, H. (2019). Supporting struggling readers with digital game-based learning. *Educational Technology Research and Development*, *67*(3), 639–663. https://doi.org/10.1007/s11423-019-09658-3

Rothou, K. M., & Padeliadu, S. (2019). Morphological processing influences on dyslexia in Greek-speaking children. *Annals of Dyslexia*. https://doi.org/10.1007/s11881-019-00184-8

Sakkan, T. (2017). *A Statistical Study of Tamil Morphology*. LAP LAMBERT Academic Publishing. Mauritius.

Sankaralingam, C., Rajendran, S., Kavirajan, B., Kumar, M. A., & Soman, K. P. (2017). Onto-thesaurus for Tamil language: Ontology-based intelligent system for information retrieval. *International Conference on Advances in Computing, Communications, and Informatics (ICACCI)*. https://doi.org/10.1109/icacci.2017.8126206

Sankaravelayuthan, R. (2021). *Semantic Change and Semantic Extension of Tamil Verbs*. Deccan College Post-graduate and Research Institute, Pune.

Sargiani, R. de A., Ehri, L. C., & Maluf, M. R. (2021). Teaching Beginners to Decode Consonant–Vowel Syllables Using Grapheme-phoneme–Phoneme Subunits Facilitates Reading and Spelling as Compared With Teaching Whole-Syllable Decoding. *Reading Research Quarterly*. https://doi.org/10.1002/rrq.432

Sargiani, R. de A., Ehri, L. C., & Maluf, M. R. (2021). Teaching Beginners to Decode Consonant–Vowel Syllables Using Grapheme-phoneme–Phoneme Subunits Facilitates Reading and Spelling as Compared With Teaching Whole-Syllable Decoding. *Reading Research Quarterly*. https://doi.org/10.1002/rrq.432

Sarma, V., Licht S., & Kalugalagedera, T. (2018). *Educational inequalities in Sri Lanka: National data and local perspectives on access, quality, and learning outcomes*. Center for Poverty Analysis, No. 10, Sri Lanka.

Sarma, V.M. (2014). Issues in the acquisition of Tamil verb morphology. In: Winskel, H., &

Padakannaya, P. (2014). *South and Southeast Asian Psycholinguistics*. Cambridge University Press.

Sarveswaran, K., Dias, G., & Butt, M. (2021). ThamizhiMorph: A morphological parser for the Tamil language. *Machine Translation*, *35*(1), 37–70. https://doi.org/10.1007/s10590-021-09261-5

Schmitterer, A. M., & Brod, G. (2021). Which data do elementary school teachers use to determine reading difficulties in their students? *Journal of Learning Disabilities*, *54*(5), 349–364. https://doi.org/10.1177/0022219420981990

Schröter, H., & Bar-Kochva, I. (2019). Reading literacy. Reading competencies in Germany and underlying cognitive skills. *Zeitschrift Für Erziehungswissenschaft*, *22*(1), 17–49. https://doi.org/10.1007/s11618-018-00864-y

Sethuraman, N., Laakso, A., & Smith, L. B. (2011). Verbs and Syntactic frames in Children's Elicited actions: A comparison of Tamil- and English-speaking children. *Journal of Psycholinguistic Research*. https://doi.org/10.1007/s10936-011-9166-2

Shakunthala, R. (2017). Problems in Learning Syntactic Aspects of Language and Remedial Teaching Measures. *Muallim Journal of Social Sciences and Humanities (MJSSH*). Volume 1- Issue 1 (1-11)

Shanahan, T. (2020). What Constitutes a Science of Reading Instruction? *Reading Research Quarterly*, 55(S1). https://doi.org/10.1002/rrq.349

Shen, W., & Park, H. (2018). The Effects of Meta-cognitive Strategies, Working Memory Capacity and Syntactic Awareness on L2 Reading Comprehension. *Journal of Pan-Pacific Association of Applied Linguistics*, *22*(2), 87–112. https://doi.org/10.25256/paal.22.2.5

Simpson, I. C., Moreno-Pérez, F. J., Rodríguez-Ortiz, I. de los R., Valdés-Coronel, M., & Saldaña, D. (2019). The effects of morphological and syntactic knowledge on reading comprehension in Spanish speaking children. *Reading and Writing*, *33*(2), 329–348. https://doi.org/10.1007/s11145-019-09964-5

Siok, W. T., & Tan, L. H. (2022). Is phonological deficit a necessary or sufficient condition for Chinese reading disability? *Brain and Language*, *226*, 105069. https://doi.org/10.1016/j.bandl.2021.105069

Sircar, S., & Nag, S. (2019). Spelling and Reading Words in Bengali: The Role of Distributed Phonology. In *Literacy studies* (pp. 161–179). https://doi.org/10.1007/978-3-030-05977-4_9

Smith, R. F. I., Snow, P., Serry, T., & Hammond, L. (2021). The Role of Background

Knowledge in Reading Comprehension: A Critical Review. *Reading Psychology*, *42*(3), 214–240. https://doi.org/10.1080/02702711.2021.1888348

Soares, A. C. C., Zuanetti, P. A., Silva, K. da, Guedes-Granzotti, R. B., & Fukuda, M. T. H. (2020). Written narrative of students with and without difficulty in syntactic awareness. *Journal of Human Growth and Development*, *30*(3), 417–424. https://doi.org/10.7322/jhgd.v30.11082

Soto, C., De Blume, A. P. G., Jacovina, M., McNamara, D. S., Benson, N., & Riffo, B. (2019). Reading comprehension and metacognition: The importance of inferential skills. *Cogent Education*, *6*(1), 1565067. https://doi.org/10.1080/2331186x.2019.1565067

Spear-Swerling, L. (2018). Structured Literacy and Typical Literacy Practices: Understanding Differences to Create Instructional Opportunities. *TEACHING Exceptional Children*, *51*(3), 201–211. https://doi.org/10.1177/0040059917750160

Srinivas, S., & Ganesh Kumar, U. (2018). Vowel-Glide Sequences in Tamil. *Shanlax International Journal of Arts, Science and Humanities*, vol. 6, no. 2, 2018, pp. 8–11.

Sunde, K., Furnes, B., & Lundetræ, K. (2019). Does Introducing the Letters Faster Boost the Development of Children's Letter Knowledge, Word Reading, and Spelling in the First Year of School? *Scientific Studies of Reading*, 1–18. https://doi.org/10.1080/10888438.2019.1615491

Templeton, S. (2020). Stages, Phases, Repertoires, and Waves: Learning to Spell and Read Words. *The Reading Teacher*, *74*(3). https://doi.org/10.1002/trtr.1951

Thangarajan, R., Natarajan, A. M., & Selvam, M. (2009). Syllable modeling in continuous speech recognition for Tamil language. *International Journal of Speech Technology*, *12*(1), 47–57. https://doi.org/10.1007/s10772-009-9058-0

Thangarasu, M., & Inbarani, H. H. (2016). Analogy removal stemmer algorithm for Tamil text corpora. In *Communications in computer and information science*. https://doi.org/10.1007/978-981-10-3274-5_6

Tibi, S., & Kirby, J. A. (2018). Investigating Phonological Awareness and Naming Speed as Predictors of Reading in Arabic. *Scientific Studies of Reading*, *22*(1), 70–84. https://doi.org/10.1080/10888438.2017.1340948

Toste, J. R., Williams, K. P., & Capin, P. (2017). Reading Big Words: Instructional Practices to Promote Multisyllabic Word Reading Fluency. *Intervention in School and Clinic*, *52*(5), 270–278. https://doi.org/10.1177/1053451216676797

Treiman, R. (2018). Teaching and Learning Spelling. *Child Development Perspectives*, 12(4),

235–239. https://doi.org/10.1111/cdep.12292

Treiman, R., Hulslander, J., Olson, R. K., Willcutt, E. G., Byrne, B., & Kessler, B. (2019). The Unique Role of Early Spelling in the Prediction of Later Literacy Performance. *Scientific Studies of Reading*, *23*(5), 437–444. https://doi.org/10.1080/10888438.2019.1573242

Vadasy, P. F., & Sanders, E. A. (2020). Introducing grapheme-phoneme correspondences (GPCs): exploring rate and complexity in phonics instruction for kindergarteners with limited literacy skills. *Reading and Writing*. https://doi.org/10.1007/s11145-020-10064-y

Vaknin-Nusbaum, V. (2021). Morphological Awareness: A Tool to Promote Reading Fluency and Accuracy in Hebrew in Students with Reading Disabilities. *Learning Disabilities Research & Practice*. https://doi.org/10.1111/ldrp.12236

Van Rijthoven, R., Kleemans, T., Segers, E., & Verhoeven, L. (2020). Response to Phonics through Spelling Intervention in Children with Dyslexia. *Reading & Writing Quarterly*, *37*(1), 1–15. https://doi.org/10.1080/10573569.2019.1707732

Van Rijthoven, R., Kleemans, T., Segers, E., & Verhoeven, L. (2021). Semantics impacts response to phonics through spelling intervention in children with dyslexia. *Annals of Dyslexia*. https://doi.org/10.1007/s11881-021-00233-1

VanMeveren, K., Hulac, D., & Wollersheim-Shervey, S. (2018). Universal Screening Methods and Models: Diagnostic Accuracy of Reading Assessments. *Assessment for Effective Intervention*, *45*(4), 255–265. https://doi.org/10.1177/1534508418819797

Vazeux, M., Doignon-Camus, N., Bosse, M.-L., Mahé, G., Guo, T., & Zagar, D. (2020). Syllable-first rather than letter-first to improve phonemic awareness. *Scientific Reports*, *10*(1). https://doi.org/10.1038/s41598-020-79240-y

Venkatraman, K., & Thiruvalluvan, V. (2021). Development of narratives in Tamil-speaking preschool children: A task comparison study. *Heliyon*, *7*(7), e07641. https://doi.org/10.1016/j.heliyon.2021.e07641

Verhoeven, L., Voeten, M., & Vermeer, A. (2019). Beyond the simple view of early first and second language reading: The impact of lexical quality. Journal of Neurolinguistics, 50, 28–36. https://doi.org/10.1016/j.jneuroling.2018.03.002

Villanueva-Villar, M., Cuevas-Alonso, M., & Saavedra, Á. (2021). Relationships between Phonological Awareness and Reading in Spanish: A Meta-Analysis. *Language Learning*, *72*(1), 113–157. https://doi.org/10.1111/lang.12471

Walgermo, B. R., Foldnes, N., Uppstad, P. H., & Solheim, O. J. (2018). Developmental

dynamics of early reading skill, literacy interest, and readers' self-concept within the first year of formal schooling. *Reading and Writing*, *31*(6), 1379–1399. https://doi.org/10.1007/s11145-018-9843-8

Wang, Y. (2018). Emergent Reading and Brain Development. *Early Childhood Education*. https://doi.org/10.5772/intechopen.82423

Wanzek, J., Petscher, Y., & Otaiba, S. A. (2019). Retention of reading intervention effects from fourth to fifth grade for students with reading difficulties. *Reading & Writing Quarterly*, *35*(3), 277–288. https://doi.org/10.1080/10573569.2018.1560379

Winskel, H. (2013). Reading and Writing in Southeast Asian Languages. *Procedia - Social and Behavioral Sciences*, *97*, 437–442. https://doi.org/10.1016/j.sbspro.2013.10.256

Winskel, H. (2020). Learning to Read in Multilingual Malaysia: A Focus on Bahasa Melayu, Tamil, and Chinese. *GEMA Online® Journal of Language Studies*, 20(1), 1–15. https://doi.org/10.17576/gema-2020-2001-01

Wojcik, E. H. (2017). The Development of Lexical-Semantic Networks in Infants and Toddlers. *Child Development Perspectives*, 12(1), 34–38. https://doi.org/10.1111/cdep.12252

Wolff, U., & Gustafsson, J. (2022). Early phonological training preceding kindergarten training: effects on reading and spelling. *Reading and Writing*, *35*(8), 1865–1887. https://doi.org/10.1007/s11145-022-10261-x

Wright, J., & Jacobs, B. (2003). Teaching Phonological Awareness and Metacognitive Strategies to Children with Reading Difficulties: A comparison of two instructional methods. *Educational Psychology*, *23*(1), 17–47. https://doi.org/10.1080/01443410303217

Xiao, Y., & Watson, M. (2017). Guidance on Conducting a Systematic Literature Review. Journal of Planning Education and Research, 39(1), 93–112. https://doi.org/10.1177/0739456x17723971

Yi, W., Lu, S., & Dekeyser, R. (2022). Orthographic, Semantic, and Contextual Influences on Initial Processing and Learning of Novel Words during Reading: Evidence from Eye Movements. *Chinese Journal of Applied Linguistics*, *45*(2), 194–219. https://doi.org/10.1515/cjal-2022-0203

Zarić, J., Hasselhorn, M., & Nagler, T. (2021). Orthographic knowledge predicts reading and spelling skills over and above general intelligence and phonological awareness. *European Journal of Psychology of Education*, *36*(1), 21–43. https://doi.org/10.1007/s10212-020-00464-7

Zhao, A., Guo, Y., & Dinnesen, M. S. (2021). The direct and indirect effects of language and cognitive skills on Chinese reading comprehension. *Reading and Writing*. https://doi.org/10.1007/s11145-021-10192-z

Ziegler, J. C., Perry, C., & Zorzi, M. (2020). Learning to Read and Dyslexia: From Theory to Intervention through Personalized Computational Models. *Current Directions in Psychological Science*, 096372142091587. https://doi.org/10.1177/0963721420915873

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Chapter 3 - The Use of the Android-Based Mydaly Application as an Alternative Communication Tool to Improve the Communication Skills of Students with Multiple Spastic Disabilities, Grade IV in Special Schools

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Chapter Highlights

- This study focuses on the use of the Android-based Mydaly application as an alternative communication tool to improve the communication skills of children with multiple disabilities, especially the spastic type, in Special Schools (SLB). The background of the study shows that communication is an important aspect in children's social and emotional development. Children with developmental disorders, such as Cerebral Palsy and hearing impairment, often experience difficulties in communicating, which can hinder their social interaction and language development.
- The purpose of the study was to explore the effectiveness of the Mydaly application in supporting the communication of children with special needs. Using a multidisciplinary approach, this study suggests that adaptive technology can help overcome the motor and sensory limitations faced by these children.
- Data shows that in Central Java, the prevalence of Cerebral Palsy and hearing impairment is quite high among children in SLB, requiring innovative solutions to support their learning.
- The results of the assessment of the communication skills of two students, KM and MS, in three stages: Pre-cycle, Cycle I, and Cycle II. In the Pre-cycle, both students obtained a total score of 3 with a percentage of 33%. After the intervention, there was an increase in Cycle I, with a total score of 6 and a percentage of 55%. In Cycle II, communication skills increased further, reaching a total score of 8 with a percentage of 88%.

Introduction

The word communication comes from communis which means to bring together or build unity between two or more people (Fadnavis et al., 2020). According the most important thing in communication is the exchange of information and the delivery of meaning from a social system or organization (af Hällström & Bosch-Sijtsema, 2024). The function of communication is not limited to delivering informat. For children, communication also builds emotional and social intelligence and forms self-confidence (Lam & Cheung, 2024). Through communication, children can express feelings of happiness, sadness, and anger so as to establish relationships with the environment. Communicating with children can get to know each other, exchange ideas, build trust, and understand. Children's communication skills develop as they begin to learn language. Children need to process language symbols into meaningful words, string words into sentences that contain messages, and understand the language conveyed by the other person. According to Piaget and Vygotsky, children's language development begins from the prelinguistic stage at the age of 0-1 years. After that, children enter the linguistic stage at the age of 1-5 years (Lakusta et al., 2024; Hsiao et al., 2024). At the age of 0-1 years, children's language development can be seen from their ability to make sounds such as crying, laughing, and babbling with simple syllables (Li et al., 2021). At the age of 1-5 years, children begin to say simple words to name objects, then develop into two words, until they can form meaningful sentences with 3-5 words. The age of 1-5 years is an important moment for children's language development. Children begin to collect a lot of vocabulary at the age of 1-3 years and at the age of 3 years children begin to apply words to interact (Bődi et al., 2023). Children with language development disorders at an early age will have difficulty communicating with people around them. Delays in language and speech in children will affect 5% of preschool children and if left untreated will affect school-age children (Bourgeois & Wendland, 2024).

Etymologically, the word communication comes from Latin, namely communicare which means to participate or to inform (Yousaf Kazmi, 2022). Based on this statement, it can be understood that communication is a process of conveying or notifying messages carried out by two or more people using verbal and non-verbal symbols. In the process, communication must run well so that the message conveyed by the communicator (message sender) can be

understood by the communicant (message recipient) so that there is a common perception (Spence et al., 2020). The main goal of the communicator is for the communicant to receive, understand, welcome, use the message conveyed, and provide a response. Therefore, the communication process can take place well if the communicant can correctly interpret the message conveyed by the subject (Hastasari et al., 2022).

However, the reality in the field is that some individuals experience barriers in communicating. For children who experience developmental disorders, most have difficulty communicating with others. Children who have motor problems due to Cerebral Palsy and brain injuries have difficulty producing words (Wotherspoon et al., 2024). Language disorders were found in 69.77% of children. Cerebral Palsy is described as a group of permanent disorders in the development of movement and body posture that causes activity limitations, this condition occurs due to progressive disorders in the brain of a developing baby or fetus (Wang et al., 2024). The position of the disorder that occurs in the brain and the function of Cerebral Palsy movement is divided into: (1) spastic, with characteristics of stiffness in some or all of the body's muscles, (2) Dyskenesia, with characteristics of athetosis (uncontrolled movements), (3) rigid, with characteristics of stiffness in the whole body so that it is difficult to bend, (4) tremor, continuous small vibrations in the eyes, hands or head, (5) ataxia, there is a disturbance in balance, walking lingually, eye and hand coordination does not function. (6) mixed type, characterized by having abnormalities in two or more of the above types.

The ability to hear is a gift from God that allows someone to learn to speak, speak, and communicate, as well as learn knowledge, life values, and socialize. However, not everyone is born with the ability to hear (Connery & Weiner, 2021). Some experience hearing loss or become deaf, which includes deafness and hard of hearing. Deafness suffered from birth or that occurs during development will cause various problems that affect the entire life and livelihood of the sufferer. Problems that will arise due to deafness include (1) in terms of perceptual, (2) communication and language (3) cognitive and intellectual fields (4) education (5) emotional fields (6) social fields (7) in terms of getting a job or vocation, (8) problems for parents and society (Boothroyd, p. 5. 1982). The initial step in dealing with the problem of deafness is to provide communication and language skills. According to Sumitro (1984, p. 2), the main goal of teaching language to deaf children is to develop verbal or oral communication skills. The goal is for deaf children to be "oral," that is, able to express, ask

questions, and discuss verbally, both with hearing people and with fellow deaf friends. The hope is that this will help them achieve two things: (1) integration into society and (2) an oral mindset, which is achieved when they can communicate verbally. However, education to develop verbal communication in deaf children requires great effort, high teacher competence, and support facilities such as sophisticated electronic equipment and appropriate language methods (Jalali et al., 2024). Other forms of communication such as gestures, mimics, and sign language are also used, but have weaknesses compared to spoken language. Therefore, education for deaf children emphasizes verbal and nonverbal communication skills (Inguscio et al., 2024).

Spastic Cerebral Palsy is a physical disorder characterized by muscle spasms, either partially or completely (Patel et al., 2024). This spastic condition causes muscles to become tense and stiff, resulting in difficulty in movement because the brain is unable to control impulses to the muscles, resulting in uncoordinated contractions (Garza-Ulloa, 2018). As a result, when doing activities, the strength used becomes opposite, making it difficult for individuals to move smoothly. Cerebral palsy (CP) is a heterogeneous condition characterized by various etiologies, impaired motor types, and different levels of severity. CP is classified based on the type of movement affected, which includes the spastic type (85% - 90% of CP cases) with hyperreflexia and upper motor neuron symptoms, the dyskinesia type (7% of CP cases) with uncontrolled movements, the dystonic type with hyperkinesia and hypotonia, the ataxid type with hypotonia and loss of coordination, and the mixed type. CP classification is also divided into two categories: pyramidal type, which involves damage to the motor areas in the cerebral cortex (such as the spastic type), and extrapyramidal type, which includes athetoid, ataxia, and dystonia types (Manto et al., 2023).

Basic Education Data (Dapodik) 2024 shows that Cerebral Palsy and Hearing Impairment are two conditions that often occur in children in Special Schools (SLB) in Central Java. Cerebral Palsy is experienced by around 1.9% of the 21,344 children in SLB, affecting their motor skills, mobility, and daily activities, thus requiring special intervention in education. In addition, around 2.4% of the total children in SLB are Deaf, which has a major impact on their communication skills and language development. These children often require hearing aids and special learning methods. Dapodik 2024 also revealed that in SLB in the Pekalongan

Residency area, Central Java, around 2.0% of 2,943 children have Cerebral Palsy, which affects their motor skills and requires special attention in education. Children with Deafness reach 2.3%, while children with multiple disabilities, namely Cerebral Palsy and Hearing Impairment, reach 2.1%. In Branch Office XI, Central Java, around 2.1% of 1,345 children have Cerebral Palsy, 2.4% have Deafness, and 1.9% have multiple disabilities. Meanwhile, in SLB N Brebes, around 2.2% of 334 children have Cerebral Palsy, 2.6% have Deafness, and 1.3% have multiple disabilities. Dapodik also noted two 5th grade children in SLB with Cerebral Palsy and Deafness, who face significant challenges in motor skills, hearing, and communication, requiring a special approach in learning and interacting.

The Need for Alternative Communication Tools in Schools

Special Schools face significant challenges in serving children with special needs, especially those with a combination of Cerebral Palsy and Deafness. Motor limitations from Cerebral Palsy make it difficult for children to move, while Deafness limits understanding of verbal instructions and communication. These children require a special approach to overcome their dual limitations, both physical and communication. Research from Padjadjaran University shows that meeting the basic needs and services for children with Cerebral Palsy requires a multidisciplinary approach, including education, rehabilitation, and skills. In SLB, education programs are often less effective due to the lack of skilled educator resources, while rehabilitation programs are more successful because they involve professional therapists who help develop children's motor functions (Mangiacotti et al., 2021). Research shows that inclusion programs for children with communication barriers, such as Deafness, face challenges in providing assistive devices to support communication in schools. The development of alternative communication tools can help children overcome the communication barriers they face every day (Sun et al., 2023).

The main problem in Special Schools in supporting children with Cerebral Palsy and Deafness is the limited technology and assistive devices that can address motor and communication barriers at the same time. Conventional methods are often ineffective, so innovative solutions such as visual communication applications and adaptive technology are needed. In addition, the lack of special training for teachers worsens the situation, because teachers need to understand children's motor needs and teach material through sign language or visual methods. AAC (Augmentative and Alternative Communication) technology such as

communication boards or smartphone applications can help, but its success depends on the teacher's readiness to integrate this technology into learning (Almusawi et al., 2021).

A major challenge in supporting the learning of children with Cerebral Palsy and Deafness is the lack of access to appropriate and adaptive technology (Núñez-Batalla et al., 2023). Children with this combination of disabilities require specialized solutions that address both motor and sensory challenges, but available assistive devices are often inadequate for both. Communication aids tend to focus on only one aspect, such as hearing or speech, without considering physical limitations (Liang et al., 2023). In addition, the lack of training for teachers in using adaptive technology further exacerbates this situation. Accessibility to technology that supports both disabilities holistically is essential to improving the effectiveness of education for these children.

Problems that exist in schools

Fifth-grade children in special needs schools with Cerebral Palsy and hearing impairments face significant challenges in communication and learning due to motor and sensory limitations. Difficulties in performing basic physical activities and understanding verbal instructions hinder their participation in class, slowing their academic and social development (YALÇIN & SADIK, 2024). The lack of adaptive technology that can address both of these barriers simultaneously exacerbates the situation (Banda et al., 2024). These children often feel isolated and have difficulty communicating with teachers and classmates. Urgent solutions include the development of appropriate adaptive technology and intensive training for teachers, so that they can provide maximum support through alternative communication technologies such as Augmentative and Alternative Communication (AAC), which have proven effective but are still constrained in their implementation (Alsalihy et al., 2024).

Problems at Home

A 5th grader in a special needs school with Cerebral Palsy and hearing impairment faces serious communication challenges, both at school and at home. Motor and sensory limitations hinder interaction with family, causing difficulties in expressing needs and feelings. Without

adaptive communication technology, communication relies on gestures and facial expressions, which are often ineffective due to the child's physical limitations. This leads to misunderstandings and frustration and affects the child's emotional well-being. The family's lack of skills in using technology or alternative communication methods exacerbates this situation. The use of visual-based Augmentative and Alternative Communication (AAC) technology can help children communicate better, improve interaction with family, and reduce dependence on parents (Gualtieri et al., 2024) .

In this study, there are several problems identified, namely lack of communication skills, limited understanding of communication, and a tendency to easily throw tantrums due to the inability to express themselves. Many students with multiple disabilities, such as Cerebral Palsy and Hearing Impairment, have difficulty in conveying their needs and desires, which results in frustration and social isolation. Therefore, the formulation of the problem in this study is how the use of the Android-based MyDali application can improve the communication skills of students with multiple disabilities in grade IV at SLB. This study also aims to assess the extent to which communication skills have improved after using the application. Thus, the purpose of this study is to explain the use of the MyDali application as an effective communication aid, and to evaluate its impact on students' communication skills. It is hoped that by understanding and analyzing the use of this application, solutions can be found to improve communication, social interaction, and independence of students in the educational environment.

Method

This research took place at SLB Negeri Brebes, the class chosen was class IV with multiple disabilities. The research was conducted at the beginning of semester II of the 2023/2024 Academic Year from January to April 2024. This research took place in the teaching and learning process every day from Monday to Thursday, with a duration of 20 minutes for each action. The data sources for this research consist of primary data and secondary data. Primary data comes from research subjects while secondary data comes from the researcher himself. This research uses qualitative and quantitative data analysis. Qualitative data analysis by describing how the use of the MyDaLi (ACC) application can improve the communication skills of students with multiple disabilities, starting from before being given action to after being given action. In quantitative data analysis by describing the comparison of the

communication skills of students with multiple disabilities starting from the initial conditions, learning outcomes in cycle 1 and results in cycle 2. The data collection technique used was interviews or observations (interviews with parents and direct observation with children), then the researcher created an assessment instrument that would be used when providing actions during observation.

The subjects of this study were two fourth-grade students with multiple disabilities, who had difficulty communicating. The first student had Cerebral Palsy which affected the ability to move the body, especially in the arms and legs, so that he needed assistance for mobility and daily activities. In addition, this student also had a hearing impairment, which made it difficult for him to understand verbal instructions and communicate without the help of alternative communication tools or methods. The second student also faced similar motor and sensory difficulties, but with more significant limitations in terms of movement coordination. Both required intensive support from teachers, physical therapy, and adaptive communication devices to better participate in learning activities. Despite having complex disabilities, both students showed high enthusiasm for learning, and with the right support, they were able to continue to develop their academic abilities and social skills.

Results

Based on the learning process that has been implemented in two research cycles, the researcher analyzed the data obtained in Cycle I as follows. At the planning stage, the researcher prepared a Learning Implementation Plan (RPP). In addition, interviews were conducted with parents of students to find out how they communicate in daily activities. The researcher also created an Android-based MyDaLi (AAC) application that displays images as answer choices. In addition, the researcher prepared an assessment instrument to measure the improvement of students' communication skills. The results of the researcher's observations on the improvement of communication skills in 2 students with multiple disabilities through the MyDaLi (ACC) application, were a total score of KM 7 with a percentage of 77% while MS 8 with a percentage of 88%.

The results obtained in cycle II showed that there had been an increase in communication.

Where at the beginning of the pre-cycle each student's total score was only 3 with a percentage of 33%, then in cycle I the total score of KM 5 with a percentage of 55%, while MS the total score was 6 with a percentage of 66%. Overall, it is explained in the following table.

Table 1. Recapitulation of the Results of the Pre-Cycle, Cycle I and Cycle II Communication Skills Assessment

No.	Assessment Items	Precycle		Cycle I		Cycle II	
		Student Initials					
		KM	MS	KM	KM	KM	MS
1.	Answering questions about activities	1	1	2	2	3	3
2.	Showing expression	1	1	2	2	2	3
3.	Answering about adjectives	1	1	1	2	2	2
	Amount	3	3	5	6	7	8
	Percentage	33%	33%	55%	66%	77%	88%

Based on the data above, it is clear that through the Android-BASED MyDaLi (ACC) application, communication in students with multiple disabilities has increased. Where the initial ability of KM and MS students was only 33%, in cycle I it increased to KM 55% and MS 66%. Then after being given treatment in cycle II, it increased to KM 77% and MS to 88%. The results of the increase in communication skills after being given treatment in the pre-cycle, cycle I and cycle II can be seen from the graph diagram below.

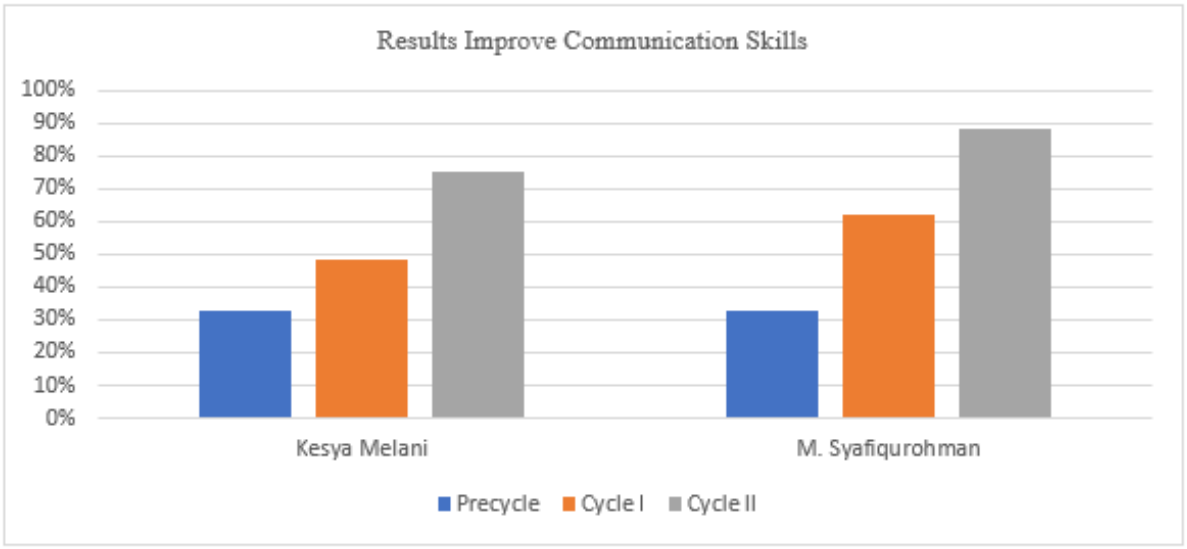

Figure 1. Results Improve Communication Skills

This shows that the Android-BASED MyDaLi (ACC) application media for students with multiple disabilities can maximize their communication skills. With good communication skills, it can help students to communicate with others. Simply put, students can understand the form of questions and can answer questions correctly.

Discussion

The Android-based MyDaLi application is designed to help children with Cerebral Palsy and Hearing Impairment at SLB N Brebes communicate more effectively, increase learning participation, and develop social skills. MyDaLi uses Augmentative and Alternative Communication (AAC) technology that supports communication through intuitive symbols, images, and icons. Augmentative & Alternative Communication (AAC) according to The American Speech Language Hearing Association (Beukelman & Light, 2020; Jhonson et al., 2008) is a field of research and clinical and educational practice that focuses on efforts to study and, if necessary, overcome temporary or permanent disorders in the production or understanding of language, both spoken and written, in individuals with severe communication disorders. This application helps overcome motor and sensory barriers and facilitates communication independence without being completely dependent on a companion. Designed with Android-based accessibility, MyDaLi is easy to use and widely available. In addition, this application supports children's learning processes, improves social interaction, and can be integrated into educational and therapeutic environments. Previous research has shown the effectiveness of AAC technology in supporting children with complex communication needs, but support from teachers, families, and technology access are still needed for successful implementation.

AAC technology can be developed in the form of low technology, such as communication boards and pictures, as well as high technology, such as computers, tablets, and digital-based speech aids (Choi & Tate, 2021). In line with Shahid et al., (2022), assistive technology is very important to help children with Cerebral Palsy communicate better. Various resources are available to improve expressive communication skills, such as articulation, word retrieval, sentence formulation, fluency, and dialogue. AAC technology is very important to help children with Cerebral Palsy communicate better. AAC includes functional communication

techniques, symbols, and interaction behaviors used to express thoughts and needs. According to Light in Da Fonte et al., (2019), AAC has four main goals: expressing needs, transferring information, building social closeness, and following social etiquette. AAC is designed with low and high technology variations to help children with Cerebral Palsy and deafness communicate effectively. This study aims to understand the role of AAC in supporting the complex communication needs of children with Cerebral Palsy and deafness (Siegel et al., 2020).

Research by Nataletti et al., (2024), shows that the developed mobile application can improve the independence and quality of life of people with Cerebral Palsy with practical solutions for daily activities. Ben Itzhak et al., (2023), found that Android-based game applications are effective in improving the vocabulary of deaf children through an interactive approach. Severino et al., (2023), explains the augmented reality based "sa…" application as an interactive learning media that helps children with speech delays understand vocabulary. Marzouk et al., (2024), revealed that the speech recognition-based Communication Board application is effective in improving the communication skills of deaf children with profound hearing loss, although it still requires further development. From this study, there is a gap that shows the need to use the Android-based MyDaLi Application to improve the communication skills of students with multiple disabilities in SLB.

This Android-based AAC is called the My Daily Life (MyDaLi) Application. The concept of this application is a series of images of activities and expressions used in everyday communication. Images can be selected by students by touching the device screen. When the image is clicked, a zooming image appears followed by sound. This aims to allow students to simultaneously learn the names of daily activities and expressions. The images selected are daily activities and expressions closest to students. Here is the appearance of MyDaLi (AAC) on an Android cellphone.

In the action stage of Cycle I, the initial communication skills of students were assessed first, with the results shown in Table 2. In the pre-cycle, KM and MS were each only able to obtain a score of 1 on three assessment items, namely answering questions about activities, showing expressions, and answering questions about adjectives, with a total score of 3 and a percentage of 33%. From these results, it can be seen that students were unable to answer questions correctly and needed full assistance from the researcher. Based on this initial

ability, the researcher used the MyDaLi (ACC) application to help improve their communication skills. In carrying out the action, the researcher first introduced the images in the MyDaLi application. These images were used as answer choices that would be chosen by students. In addition, questions according to the images in the application were asked in stages. In the observation stage, the researcher analyzed the results of improving students' communication skills through the Android-based MyDaLi application. The assessment results in Cycle I showed that KM obtained a total score of 5 with a percentage of 55%, while MS achieved a score of 6 with a percentage of 66%. Although there was an increase from the pre-cycle, this result was still below the KKM.

Figure 2. MyDaLi (AAC) display on Android phones

Reflection from Cycle I showed that although there was an increase, the results were still not optimal. Comparative data between the pre-cycle and Cycle I showed an increase from 33% to 55% for KM and from 33% to 66% for MS. The shortcomings in Cycle I were used as a reference for improvements in Cycle II. In Cycle II, the researcher made several improvements in the planning and implementation of actions. The MyDaLi application was updated by displaying schemes such as "I want," "I feel," and "I..." which were used as question aids. Questions were given in stages, with clearer and different answer choices to facilitate student understanding. The researcher also gave questions repeatedly and used diversions to ensure that students really understood the questions and answers. Observations in Cycle II showed significant improvements. KM achieved a total score of 7 with a

percentage of 77%, while MS achieved a total score of 8 with a percentage of 88%, as shown in Table 5. Based on the reflection of Cycle II, the results showed a significant increase from Cycle I, with KM increasing from 55% to 77% and MS from 66% to 88%. These results indicate that the Android-based MyDaLi application is effective in improving the communication skills of students with multiple disabilities, and the KKM target has been achieved, so no further handling is required in the next cycle.

Work indicators can be seen from the ability of students to answer questions to improve communication skills, both communication with peers, parents, and teachers. In Cycle I, the research began with the planning stage which included the preparation of the Learning Implementation Plan (RPP) (Attachment 1), preparation of observation and interview guidelines (Attachment 2), and preparation of the Android-based MyDaLi application used on Android phones, with picture features as answer choices in the application. In the action stage, the researcher first explained the pictures that were the answer choices in the MyDaLi application, followed by an explanation of the application usage flow so that the subjects understood the material to be presented. The researcher also explained the direction and choice of questions that must be answered by the subjects. Furthermore, the observation stage was carried out to analyze research data with the aim of determining the process of improving communication skills in students with multiple disabilities. After the action was carried out, reflection was carried out to evaluate the extent to which the use of the MyDaLi application could improve students' communication skills. This reflection also includes an analysis of the advantages and disadvantages of the actions taken, so that they can be improved in the next cycle. After Cycle I was completed, the research continued to Cycle II. The steps in Cycle II are basically the same as Cycle I, but with improvements in planning and providing actions based on the results of reflection from Cycle I. The results of observations and data analysis in Cycle II show an improvement from the results obtained in Cycle I, because Cycle II is an improvement and refinement of the actions that have been carried out previously.

Conclusion

The recapitulation results of the assessment of the communication skills of two students, namely KM and MS, in three assessment stages: Pre-cycle, Cycle I, and Cycle II. The assessment was carried out on three aspects, namely the ability to answer questions about activities, show expressions, and answer about adjectives. In the Pre-cycle stage, both KM

and MS received a score of 1 for the three assessment items, with a total score of 3 and a percentage of 33%. After the intervention in Cycle I, there was an increase in their communication skills. KM received scores of 2, 2, and 2, while MS received scores of 1, 2, and 2. The total score increased to 6 with a percentage of 55%. In Cycle II, there was a more significant increase, where KM received scores of 3, 2, and 3, while MS received a score of 3 for all assessment items. The total score in this cycle was 8 with a percentage of 88%. Overall, this table shows a consistent increase in the communication skills of both students from the pre-cycle to cycle II.

Recommendations

Researchers suggest that learning for students with multiple disabilities should use visual media. Through visual media, it is easier for students to understand questions and provide answers. One of them is the Android-BASED MyDaLi (ACC) application visual media. Where the form of questions and questions is packaged virtually by displaying sound, thus helping students to understand the concept of communication. If their understanding of communication is good, then students can communicate with anyone.

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References

af Hällström, A., & Bosch-Sijtsema, P. (2024). “I can say things I wouldn’t normally say”: Changing project delivery implementation and social networks as drivers of institutional change in Nordic infrastructure projects. *Project Leadership and Society*, *5*, 100117. https://doi.org/10.1016/j.plas.2024.100117

Almusawi, H. A., Durugbo, C. M., & Bugawa, A. M. (2021). Innovation in physical education: Teachers’ perspectives on readiness for wearable technology integration.

Computers & Education, *167*, 104185. https://doi.org/10.1016/j.compedu.2021.104185

Alsalihy, S. T. H., Ahmed, A. N., Salih, G. H. A., M-Ridha, M. J., & Falahi, O. A. AL. (2024). Removal of pharmaceutical and personal care products (PhPCPs) using different low-cost materials as substrates in the vertical, horizontal, and hybrid flow systems of constructed wetland – A review. *Environmental Technology & Innovation*, *35*, 103647. https://doi.org/10.1016/j.eti.2024.103647

Banda, L. O. L., Banda, C. V., Banda, J. T., Hlaing, T. T., & Mwaene, E. (2024). Assessing farmers' knowledge of environmental policy along the Ayeyarwady River: Strides towards the Indian Ocean marine life safety. *Heliyon*, *10*(16), e35503. https://doi.org/10.1016/j.heliyon.2024.e35503

Ben Itzhak, N., Franki, I., Jansen, B., Kostkova, K., Wagemans, J., & Ortibus, E. (2023). Usability and user experience of an individualized and adaptive game-based therapy for children with cerebral visual impairment. *International Journal of Child-Computer Interaction*, *35*, 100551. https://doi.org/10.1016/j.ijcci.2022.100551

Bődi, C. B., Ortega, D. P., Hawkins, L. B., James, T. G., & Bright, M. A. (2023). Parents' and professionals' perspectives on school-based maltreatment prevention education for children with intellectual and developmental disabilities. *Child Abuse & Neglect*, *145*, 106428. https://doi.org/10.1016/j.chiabu.2023.106428

Bourgeois, A., & Wendland, J. (2024). Mental health disorder in preschool children: Do we have the best tools possible to detect it? *Neuropsychiatrie de l'Enfance et de l'Adolescence*, *72*(4), 182–193. https://doi.org/10.1016/j.neurenf.2024.04.005

Choi, J., & Tate, J. A. (2021). Evidence-Based Communication with Critically Ill Older Adults. *Critical Care Clinics*, *37*(1), 233–249. https://doi.org/10.1016/j.ccc.2020.09.002

Connery, C., & Weiner, J. M. (2021). Teachers making sense of undocumented status and their responsibilities to undocumented students: A critical perspective. *Teaching and Teacher Education*, *98*, 103232. https://doi.org/10.1016/j.tate.2020.103232

Da Fonte, M. A., Boesch, M. C., Young, R. D., & Wolfe, N. P. (2019). *Communication system identification for individuals with complex communication needs: the need for effective feature matching* (hal. 171–228). https://doi.org/10.1016/bs.irrdd.2019.07.002

Fadnavis, S., Najarzadeh, A., & Badurdeen, F. (2020). An Assessment of Organizational Culture Traits Impacting Problem Solving for Lean Transformation. *Procedia Manufacturing*, *48*, 31–42. https://doi.org/10.1016/j.promfg.2020.05.017

Garza-Ulloa, J. (2018). Case studies of applied Biomechatronics solutions based on

mathematical models. In *Applied Biomechatronics using Mathematical Models* (hal. 525–626). Elsevier. https://doi.org/10.1016/B978-0-12-812594-6.00007-X

Gualtieri, L., Öhler, M., Revolti, A., & Dallasega, P. (2024). A visual management and augmented-reality-based training module for the enhancement of short and long-term procedural knowledge retention in complex machinery setup. *Computers & Industrial Engineering*, *196*, 110478. https://doi.org/10.1016/j.cie.2024.110478

Hastasari, C., Setiawan, B., & Aw, S. (2022). Students' communication patterns of islamic boarding schools: the case of Students in Muallimin Muhammadiyah Yogyakarta. *Heliyon*, *8*(1), e08824. https://doi.org/10.1016/j.heliyon.2022.e08824

Hsiao, Y., Dawson, N. J., Banerji, N., & Nation, K. (2024). A corpus-based developmental investigation of linguistic complexity in children's writing. *Applied Corpus Linguistics*, *4*(1), 100084. https://doi.org/10.1016/j.acorp.2024.100084

Inguscio, B. M. S., Cartocci, G., Sciaraffa, N., Nicastri, M., Giallini, I., Aricò, P., Greco, A., Babiloni, F., & Mancini, P. (2024). Two are better than one: Differences in cortical EEG patterns during auditory and visual verbal working memory processing between Unilateral and Bilateral Cochlear Implanted children. *Hearing Research*, *446*, 109007. https://doi.org/10.1016/j.heares.2024.109007

Jalali, M., Luo, Y., Caulfield, L., Sauter, E., Nefedov, A., & Wöll, C. (2024). Large language models in electronic laboratory notebooks: Transforming materials science research workflows. *Materials Today Communications*, *40*, 109801. https://doi.org/10.1016/j.mtcomm.2024.109801

Lakusta, L., Wefferling, J., Elgamal, K., & Landau, B. (2024). "Dividing the labor": Lexical verbs and the linguistic encoding of physical support in 2- to 4.5-year-old children. *Journal of Experimental Child Psychology*, *238*, 105803. https://doi.org/10.1016/j.jecp.2023.105803

Lam, R., & Cheung, C. (2024). Synthesizing cultural intelligence, emotional labor, and job satisfaction in the concept of a social cognitive model. *Journal of Hospitality and Tourism Management*, *60*, 280–290. https://doi.org/10.1016/j.jhtm.2024.08.001

Li, J., Hasegawa-Johnson, M., & McElwain, N. L. (2021). Analysis of acoustic and voice quality features for the classification of infant and mother vocalizations. *Speech Communication*, *133*, 41–61. https://doi.org/10.1016/j.specom.2021.07.010

Liang, R., Ju, M., Kong, F., Xie, Y., & Tang, G. (2023). A Non-Intrusive speech quality

evaluation algorithm for hearing aids via an auxiliary training task. *Applied Acoustics, 206*, 109312. https://doi.org/10.1016/j.apacoust.2023.109312

Mangiacotti, A. M. A., Franco, F., Hsu, M. H., & Biasutti, M. (2021). Evaluating a continuing professional development course on cognitive functions for Music Therapists working in care homes. *The Arts in Psychotherapy*, *74*, 101800. https://doi.org/10.1016/j.aip.2021.101800

Manto, M., Serrao, M., Filippo Castiglia, S., Timmann, D., Tzvi-Minker, E., Pan, M.-K., Kuo, S.-H., & Ugawa, Y. (2023). Neurophysiology of cerebellar ataxias and gait disorders. *Clinical Neurophysiology Practice*, *8*, 143–160. https://doi.org/10.1016/j.cnp.2023.07.002

Marzouk, Y. S., El-Sherbiny, E., & Refaat, T. (2024). The architecture design checklist of classrooms for children with cochlear implant in rehabilitation centers. *Results in Engineering*, *22*, 102175. https://doi.org/10.1016/j.rineng.2024.102175

Nataletti, S., Banerjee, A., Macaluso, R., Prokup, S., Jayaraman, A., & Wong, A. W. K. (2024). Developing a mobile exercise program for individuals with Spinal Cord Injury: Stakeholder perceptions of app features and implementation determinants. *Disability and Health Journal*, *17*(4), 101667. https://doi.org/10.1016/j.dhjo.2024.101667

Núñez-Batalla, F., Jáudenes-Casaubón, C., Sequí-Canet, J. M., Vivanco-Allende, A., & Zubicaray-Ugarteche, J. (2023). Deaf children with additional disabilities (AD+): CODEPEH recommendations. *Acta Otorrinolaringologica (English Edition)*, *74*(6), 386–396. https://doi.org/10.1016/j.otoeng.2022.10.008

Patel, D. R., Bovid, K. M., Rausch, R., Ergun-Longmire, B., Goetting, M., & Merrick, J. (2024). Cerebral palsy in children: A clinical practice review. *Current Problems in Pediatric and Adolescent Health Care*, 101673. https://doi.org/10.1016/j.cppeds.2024.101673

Severino, C., Plakans, L., Lee, K., & Susanah. (2023). Selected bibliography of recent scholarship in second language writing. *Journal of Second Language Writing*, *59*, 100976. https://doi.org/10.1016/j.jslw.2023.100976

Shahid, N. M. I., Law, E. L.-C., & Verdezoto, N. (2022). Technology-enhanced support for children with Down Syndrome: A systematic literature review. *International Journal of Child-Computer Interaction*, *31*, 100340. https://doi.org/10.1016/j.ijcci.2021.100340

Siegel, M., McGuire, K., Veenstra-VanderWeele, J., Stratigos, K., King, B., Bellonci, C., Hayek, M., Keable, H., Rockhill, C., Bukstein, O. G., & Walter, H. J. (2020). Practice Parameter for the Assessment and Treatment of Psychiatric Disorders in Children and

Adolescents With Intellectual Disability (Intellectual Developmental Disorder). *Journal of the American Academy of Child & Adolescent Psychiatry*, *59*(4), 468–496. https://doi.org/10.1016/j.jaac.2019.11.018

Spence, P. R., Lin, X., Lachlan, K. A., & Hutter, E. (2020). Listen up, I've done this before: The impact of self-disclosure on source credibility and risk message responses. *Progress in Disaster Science*, *7*, 100108. https://doi.org/10.1016/j.pdisas.2020.100108

Sun, T., Bowles, R. P., & Douglas, S. N. (2023). Chinese-English speaking family perspectives of augmentative and alternative communication use with their children. *Journal of Communication Disorders*, *102*, 106315. https://doi.org/10.1016/j.jcomdis.2023.106315

Wang, X., Zang, J., Yang, Y., Li, K., Ye, D., Wang, Z., Wang, Q., Wu, Y., & Luan, Z. (2024). Human neural stem cells transplanted during the sequelae phase alleviate motor deficits in a rat model of cerebral palsy. *Cytotherapy*. https://doi.org/10.1016/j.jcyt.2024.07.012

Wotherspoon, J., Whittingham, K., Sheffield, J., & Boyd, R. N. (2024). Randomised controlled trial of an online cognitive training program in school-aged children with cerebral palsy. *Research in Developmental Disabilities*, *150*, 104752. https://doi.org/10.1016/j.ridd.2024.104752

Yalçın, D. O., & Sadık, D. F. (2024). Examining the cognitive and affective changes in students through the implementation process of the physics curriculum based on an interdisciplinary context-based learning approach. *Thinking Skills and Creativity*, 101672. https://doi.org/10.1016/j.tsc.2024.101672

Yousaf Kazmi, S. (2022). The etymology of microbial nomenclature and the diseases these cause in a historical perspective. *Saudi Journal of Biological Sciences*, *29*(11), 103454. https://doi.org/10.1016/j.sjbs.2022.103454

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Citation

Lutfi, M., Hermanto, H., Herwanto, A., Prihatmojo, A., Marwan (2024). The Use of the Android-Based Mydaly Application as an Alternative Communication Tool to Improve the Communication Skills of Students with Multiple Spastic Disabilities, Grade IV in Special Schools. In A. A. Khan & O. T. Ozturk (Eds.), *Studies on Social and Education Sciences 2024* (pp. 62-80). ISTES.

Chapter 4 - A Survey on Students' Perceptions of GenAI in Higher Education

Omid Noroozi, Nafiseh Taghizadeh Kerman, Seyyed Kazem Banihashem

Chapter Highlights

- While Generative Artificial Intelligence (GenAI) tools are increasingly being used by students in higher education, we still lack insight into their views on its use and potential applications.
- This study explores students' perceptions of GenAI tools across five key dimensions: learning performance, motivation, effort expectancy, trustworthiness, and intention to use.
- Data were collected through the spread of an online survey among 940 higher education students enrolled in life sciences courses at a Dutch university during the 2023-2024 academic year.
- The results indicated that students generally found GenAI tools useful, easy to use, and moderately trustworthy.
- They reported that GenAI tools help with task completion and improve learning performance.
- Effort expectancy was high, with students finding the tools intuitive and easy to learn. However, motivation levels were moderate, and there was variability in intention to use. Some students expressed a strong desire to continue using GenAI tools, while others were uncertain or less inclined to engage with them in the future.
- These findings suggest that while GenAI tools show promise in supporting students' performance, there are challenges related to student motivation and long-term intention to use.
- The study provides insights for educators and institutions aiming to integrate GenAI tools effectively into higher education.

Introduction

Generative Artificial Intelligence (GenAI) is rapidly transforming the landscape of higher education, offering unprecedented opportunities to enhance teaching, learning, and assessment. Understanding students' perceptions of this technology is critical to harnessing its potential effectively (Farrokhnia et al., 2024). As primary stakeholders in the educational process, students' attitudes and beliefs about GenAI significantly influence how these tools are adopted, used, and ultimately impact their academic performance and experience.

The emergence of GenAI tools like ChatGPT showcased the potential for AI to streamline educational processes and provide personalized learning experiences. These tools can help students access immediate feedback, generate ideas, and explore new forms of creativity (Banihashem et al., 2024). However, they also raise important questions about ethics, academic integrity, and equitable access. Exploring students' perceptions allows educators and policymakers to address these concerns and create strategies that align with students' needs, ensuring that GenAI complements rather than complicates their learning journey.

GenAI tools are increasingly and significantly influencing higher education. These tools offer capabilities like content generation and personalized support, which have the potential to reshape students' learning experiences (Farrokhnia, et al., 2024; Noroozi et al., 2024). However, the impact of GenAI tools depends heavily on students' perceptions, which encompass various psychological and behavioral dimensions (Daher and Hussein, 2024). Students' perceptions and attitudes, whether positive or negative, play a crucial role in determining their willingness to adopt and effectively use GenAI tools in educational contexts (Zawacki-Richter et al., 2020). Students' negative and positive perceptions of and attitudes towards GenAI tools can determine whether students are willing to use and apply GenAI tools are not. Investigating how students perceive these tools can reveal the opportunities and challenges associated with their integration into academic settings (Dwivedi et al., 2023). Understanding students' learning performance, motivation, effort expectancy, trustworthiness, and intention to use can guide educators and institutions in designing effective strategies for GenAI tools adoption that align with educational goals and ethical considerations (Zawacki-Richter et al., 2019).

Student perceptions involve several key dimensions, including perceived learning performance (students' beliefs about the extent to which GenAI tools contribute to their learning outcomes and academic success), perceived motivation (the extent to which students believe that using GenAI tools enhances their enthusiasm, motivation, and drive to learn or complete academic tasks), perceived effort expectancy (the degree to which students believe that GenAI tools are easy to use and require minimal effort to adopt), perceived trustworthiness (to the extent to which students believe that GenAI tools are reliable, accurate, and capable of providing trustworthy outputs or recommendations in educational contexts), and intention to use (the likelihood or willingness of students to adopt and utilize GenAI tools for educational purposes). These dimensions play a crucial role in determining how students interact with GenAI tools and the extent to which these tools are embraced in academic environments (Venkatesh et al., 2012).

One of the key reasons to focus on students' perceptions is to shape effective integration strategies for GenAI in higher education. When students view these tools positively, recognizing their ability to support learning, institutions can design interventions that maximize these benefits (Akhteh et al., 2022a, 2022b). For example, embedding GenAI into collaborative learning environments or adaptive learning platforms can make education more personalized and engaging. At the same time, addressing negative perceptions, such as concerns about over-reliance on AI or the loss of critical thinking skills, ensures that the integrati on of technology does not undermine educational objectives (Banihashem et al., 2024).

Understanding students' perceptions also sheds light on the need to foster digital literacy and critical thinking. While GenAI offers convenience and efficiency, students must develop the skills to evaluate AI-generated outputs critically. Without these skills, there is a risk of overdependence on AI, potentially undermining students' ability to think independently and solve complex problems. By understanding how students perceive and interact with these tools, educators can design targeted interventions that promote responsible and informed use of technology (Noroozi et al., 2024).

Another important dimension of students' perceptions relates to the ethical implications of using GenAI. Questions about plagiarism, bias in AI-generated content, and data privacy

have become central to discussions about AI in education. By engaging with students' views, educators can facilitate meaningful conversations about the responsible use of AI and co-create policies that reflect shared values. This approach not only encourages ethical behavior but also fosters a sense of accountability and trust between students and institutions (Noroozi et al., 2024).

This study seeks to explore these factors, addressing the research question: How do students perceive the use of GenAI tools in higher education in terms of learning performance, motivation, effort expectancy, trustworthiness, and intention to use? By addressing this research question, we aim to provide a comprehensive understanding of how students perceive the use of GenAI tools in higher education, focusing on their impact on learning performance, motivation, effort expectancy, trustworthiness, and intention to use. This insight will help educators, policymakers, and developers design more effective strategies for integrating GenAI tools into educational practices, ensuring they meet students' needs and foster positive learning outcomes.

Method

Context and Participants

This exploratory and survey-based study was conducted at a Dutch university and involved 940 higher education students enrolled in five life sciences courses during the 2023-2024 academic year. Of these, 722 participants were included in the final analysis, as 218 students (23%) did not complete the survey. The demographic information of the participants is listed in Table 1.

Table 1: Demographic Information of the Study Sample

Variable	Category	N	%
Education Level	Bachelor's students	285	37.3

	Master's students	479	62.7
Academic Year	First year	246	32.2
	Second year	265	34.7
	Third year	153	20.0
	Fourth year	63	8.2
	Other years	35	4.6
Native Language	Dutch	545	71.3
	Non Dutch	216	28.3
Gender	Female	398	52.1
	Male	322	42.1

Measurements and Analysis

To assess students' perceptions of using GenAI tools, a questionnaire was developed based on frameworks by Venkatesh et al. (2012), Gulati et al. (2019), Chatterjee et al. (2020), and the UNESCO report. The questionnaire included 16 items evaluating five components: learning performance (e.g., I find GenAI useful for my learning), motivation (e.g., using GenAI is fun), effort expectancy (e.g., learning how to use GenAI is easy for me), trustworthiness (e.g., I can trust the information presented to me by GenAI), and intention to use (e.g., I intend to continue using GenAI in the future). Responses were measured on a five-point Likert scale ranging from "strongly disagree" (1) to "strongly agree" (5). A score of 5 indicates a highly positive perception while a score of 1 reflects a negative perception, indicating strong disagreement. The scale demonstrated high reliability, with a Cronbach's alpha of 0.95, and descriptive analyses provided mean and standard deviation for each item and component.

Results

The findings revealed nuanced insights into students' perceptions of GenAI tools across five dimensions. Learning performance, with an overall mean of 3.51, indicated that students generally find GenAI useful for their learning performance and productivity. Among the

items, the highest-rated statement was that using GenAI helps students accomplish tasks more quickly (M = 3.63, SD = 1.43), while the lowest-rated was its impact on productivity (M = 3.41, SD = 1.44). For motivation, the results showed a moderate level of enjoyment, with an overall mean of 3.11. Students found GenAI moderately fun (M = 3.21, SD = 1.26), though entertainment was rated slightly lower (M = 3.00, SD = 1.27). The effort expectancy was rated relatively high (M = 3.53), suggesting that students perceive GenAI as easy to learn and use. Among the items, the statement "I find GenAI easy to use" received the highest score (M = 3.71, SD = 1.30). However, trustworthiness in GenAI scored mixed results. While students expressed skepticism about its accuracy, as indicated by high agreement with the statement "Educational content created by GenAI is NOT always correct" (M = 4.37, SD = 1.12), their overall trustworthiness level in the tool was moderate (M = 3.60, SD = 0.73). Finally, intention to use showed variability, with an overall mean of 3.11. While some students indicated an intent to continue using GenAI (M = 3.77, SD = 1.37), others were less certain about consistent future usage (M = 2.42, SD = 1.25) (see Figure 1).

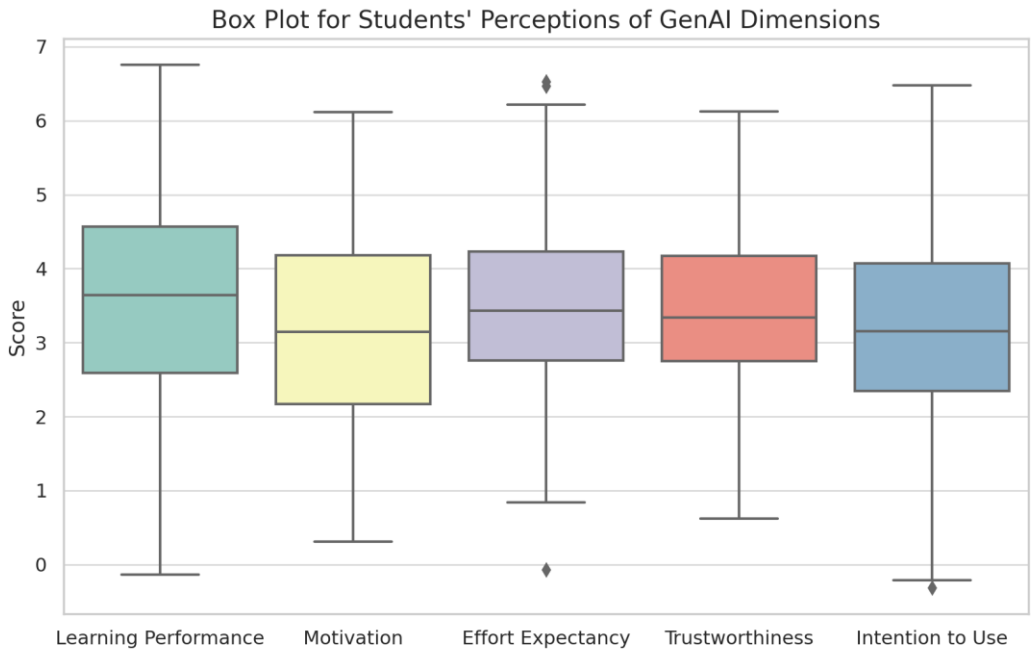

Figure 1: Descriptive Statistics of Students' Perceptions of Using GenAI in Higher Education

Discussion and Conclusion

Capturing students' perceptions is not without its challenges. Attitudes toward GenAI can vary widely based on factors such as academic discipline, prior exposure to technology, and

cultural background. Additionally, perceptions may evolve as students gain more experience with these tools, requiring continuous engagement and research. The gap between students' stated perceptions and their actual use of GenAI further complicates the picture, underscoring the need for nuanced and ongoing exploration.

Addressing these complexities requires a multifaceted approach. Research that combines surveys, interviews, and observational studies can provide a comprehensive understanding of students' perceptions. Such efforts should not only capture the benefits students see in GenAI but also delve into the barriers and concerns they face. Involving students in the design and implementation of GenAI tools ensures that these technologies align with their needs and expectations, increasing the likelihood of acceptance and effective use.

Our findings highlight both the opportunities and challenges associated with integrating GenAI tools into higher education. In general, The analysis of the data highlights notable trends across key dimensions of students' perceptions regarding the use of GenAI tools in higher education. Among the examined factors, "trustworthiness" received the highest average score, indicating that students generally perceive these tools as reliable and credible. This trustworthiness may serve as a foundation for their willingness to engage with GenAI tools in academic settings. Additionally, effort expectancy and learning performance were found to be rated relatively high, suggesting that students found these tools both easy to use and effective in enhancing their academic success. These scores reflect the potential of GenAI tools to support students in achieving their educational objectives. However, motivation and intention to use both received low scores, highlighting potential challenges in fostering enthusiasm and sustained engagement with these tools. These lower ratings may point to barriers such as a lack of intrinsic interest or concerns about the long-term value of GenAI in their studies.

Results related to perceived usefulness and trustworthiness, align with technology adoption frameworks, such as the Unified Theory of Acceptance and Use of Technology (UTAUT), which emphasize usability and trust as critical components of adoption (Venkatesh et al., 2012; Dwivedi et al., 2023). Results related to low motivation are in line with previous studies that highlight motivation as a key barrier to the adoption of educational technologies (Zawacki-Richter et al., 2019; Daher & Hussein, 2024). To maximize the potential of GenAI

tools for educational success, institutions must address these barriers by implementing strategies that enhance intrinsic motivation and clearly communicate the tools' long-term benefits. For instance, integrating GenAI into meaningful, goal-oriented tasks can help reinforce its utility while fostering engagement. To provide a more holistic picture, future research should explore the broader implications of GenAI adoption, particularly its perceived impact on critical thinking, creativity, and ethical considerations, to ensure its alignment with educational objectives and sustainable integration.

Institutions can also play a proactive role by offering training and support to help students navigate the opportunities and challenges of GenAI. Workshops, tutorials, and resources that focus on both technical and ethical aspects of AI use can empower students to engage with these tools responsibly. Additionally, involving students in decision-making processes about AI policies fosters a sense of ownership and trust, ensuring that institutional strategies resonate with the experiences and aspirations of the student body. Evaluating the long-term impact of GenAI on students' learning experiences is equally important. By monitoring outcomes such as academic performance, student satisfaction, and perceptions of academic integrity, institutions can refine their approaches and ensure that AI integration contributes to meaningful educational improvements. This ongoing assessment helps create an adaptive framework that evolves alongside technological advancements and students' changing needs (Noroozi et al., 2024). As higher education embraces the possibilities of GenAI, understanding students' perceptions is not merely an academic exercise but a practical imperative. These insights provide the foundation for thoughtful, inclusive, and effective integration of AI into educational practices. By listening to and addressing students' perspectives, institutions can create a learning environment that leverages the strengths of AI while safeguarding the principles of equity, ethics, and academic excellence. In doing so, they not only prepare students for the demands of an AI-driven world but also reaffirm the role of education as a catalyst for growth and innovation.

References

Akhteh, M. P., Noroozi, O., & Banihashem, S. K. (2022a, March). Students' motivation, satisfaction, and perceived learning using online peer feedback in the context of

argumentative essay writing. In The International Society for Technology, Education and Science (ISTES).

Akhteh, M. P., Farrokhnia, M., Banihashem, S. K., & Noroozi, O. (2022b). The Relationship between Students' Satisfaction and Motivation and their Perceived Learning Outcome in an Online Peer Feedback Module. In *Studies on Education, Science, and Technology* (pp. 297-310). ISTES.

Banihashem, S. K., Taghizadeh Kerman, N., Noroozi, O., Moon J., Drachsler, H. (2024). Feedback sources in essay writing: Peer generated or AI-generated feedback?. *International Journal of Educational Technology in Higher Education*, *21*(23), 1-15. https://doi.org/10.1186/s41239-024-00455-4.

Daher, W., & Hussein, A. (2024). Higher Education Students' Perceptions of GenAI Tools for Learning. *Information (2078-2489)*, *15*(7). https://doi.org/10.3390/info15070416

Dwivedi, Y. K., Hughes, D. L., Kar, A. K., Baabdullah, A. M., Grover, P., & Abbas, R. (2023). Artificial Intelligence (AI): Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice, and policy. *International Journal of Information Management*, *66*, 102573. https://doi.org/10.1016/j.ijinfomgt.2022.102573

Farrokhnia, M., Banihashem, S. K., Noroozi, O., & Wals, A. (2024). A SWOT analysis of ChatGPT: Implications for educational practice and research. *Innovations in Education and Teaching International*, *61*(3), 460-474. https://doi.org/10.1080/14703297.2023.2195846

Noroozi, O., Soleimani, S., Farrokhnia, M., & Banihashem, S.K. (2024). Generative AI in education: Pedagogical, theoretical, and methodological perspectives. *International Journal of Technology in Education*, 7(3), 373-385. https://doi.org/10.46328/ijte.845

Venkatesh, V., Thong, J. Y. L., & Xu, X. (2012). Consumer acceptance and use of information technology: Extending the unified theory of acceptance and use of technology (UTAUT2). *MIS Quarterly*, *36*(1), 157–178. https://doi.org/10.2307/41410412

Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education – where are the educators? *International Journal of Educational Technology in Higher Education, 16*(1), 1-27. https://doi.org/10.1186/s41239-019-0171-0

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Chapter 5 - Point Proven: Integrating Real Analysis Concepts into an Educational Game

Gantina Rachmaputri, Joshia Tanumihardja

Chapter Highlights

- The Traditional teaching methods often need help to effectively engage students in complex mathematical subjects, particularly in real analysis.
- This research explores "Point Proven," an educational game designed to bridge this gap by integrating mathematical proofs and axioms into an interactive, gamified environment.
- Developed through a rapid prototype framework, the game aims to foster deeper understanding and enjoyment in learning real analysis.
- Playtesting involved 100 participants who took pre- and post-tests on real analysis concepts.
- The results showed a positive correlation between gameplay and improved comprehension, suggesting that gamified learning tools can be valuable supplements to traditional teaching methods.

Introduction

The mathematics is a cornerstone of education, yet teaching abstract concepts, particularly in fields like real analysis, presents a significant challenge. According to the OECD's Programme for International Student Assessment (PISA), Indonesian students consistently perform below the international average in mathematics, scoring 366 compared to the global average of 472 (PISA, n.d.; see Figure 1). This trend reveals widespread issues with student engagement and comprehension, and the pandemic further exacerbated these challenges by forcing a shift to online learning. In Indonesia, 60% of students reported school closures lasting over three months, potentially impacting math proficiency. Traditional math teaching methods, which often focus on rote memorization and step-by-step procedures, fail to foster the critical thinking and problem-solving skills essential for real-world applications. The PISA assessment evaluates 15-year-olds' ability to apply their reading, mathematics, and science knowledge to practical challenges.

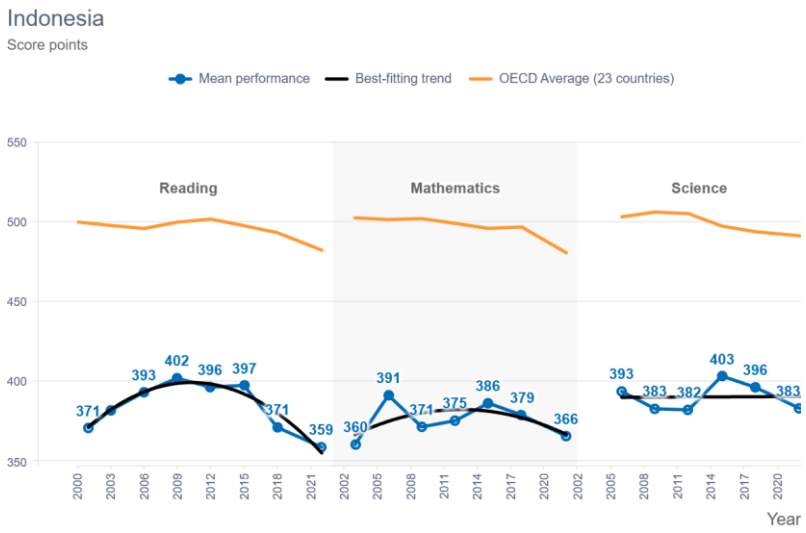

Figure 1. Trends in Reading, Mathematics and Science in Indonesia (PISA 2022 results, n.d.)

In Indonesia, the education system emphasizes memorization over problem-solving, leading students to master procedures without fully understanding their meaning. While this method is effective for memorizing large volumes of information, it must be improved to promote the critical thinking needed to apply mathematical concepts in various contexts. In contrast, active learning through problem-solving encourages students to develop new knowledge independently, though it requires more time and resources (N. Akhter, 2015).

The Indonesian gaming market has also rapidly expanded, especially post-COVID-19, as people shifted from traditional to digital games (Sanjaya, 2020). By 2022, an estimated 185 million Indonesians were gamers, comprising 89% of the population aged 15 and above (Kameke, 2022; Total Population of Age 15 and above by Age Group, 2022, 2024). This growth underscores Indonesia's strong market potential, which is supported by a thriving game development industry gaining international recognition. Indonesian e-sports teams and game studios are increasingly acknowledged globally, reflecting the country's expanding role in the gaming world (Fauzia, 2024). The gaming community's enthusiasm surged after COVID-19, driving demand for games and fostering interest in game development across Indonesia. However, despite the potential for games to educate and showcase Indonesian traditions and culture, many titles lack educational content, focusing more on entertainment. Games focusing on cultural education often struggle to attract public interest, as audiences tend to find them less engaging when promoted primarily for educational purposes.

This study emerges from a central question: Could an educational game improve students' understanding of these abstract mathematical concepts? Specifically, could a game-based approach, or gamification, enhance motivation and engagement in learning mathematics? Moreover, if so, how practical would it be to use this approach to make math more accessible and appealing for students? The study has three main objectives in exploring these questions. First, it aims to develop an educational game that merges learning with interactive engagement by weaving real analysis concepts into gameplay. Second, it tests the effectiveness of "Point Proven" as a learning tool to improve students' grasp of mathematical proofs and axioms. Finally, the study examines whether this approach can meaningfully boost students' engagement and interest in mathematics, especially in challenging areas like real analysis. This research used a rapid prototype development framework, where iterative testing and refinement allowed for quick adjustments based on player feedback. Data collection involved surveys and playtesting, providing quantitative and qualitative insights into player engagement, comprehension, and game usability.

Method

The development of "Point Proven" followed a rapid prototype framework, allowing for flexibility and continuous iteration. This approach involves four main stages: identification,

development, implementation, and revision. With each iteration, feedback from playtesting sessions guided adjustments, making it possible to quickly refine the game's design to meet educational goals better and enhance player engagement. Each game version became more aligned with boosting comprehension and maintaining student interest.

Designers must apply emerging theories before testing game designs to balance educational and entertainment goals effectively. This section introduces several critical theories relevant to educational games, each contributing unique insights into how games can foster learning.

1. Rapid Prototype Development Framework

The rapid prototype development framework streamlines the design process into four key stages: Identification, Development, Implementation, and Revision. It begins with identifying the game's audience, content, and requirements. From there, developers create a basic prototype focused on fulfilling essential goals, followed by implementation through playtesting. The final stage involves reviewing and refining the product, looping back to testing until the game meets its objectives. This iterative process allows developers to enhance quality while reducing development time, leading to a more polished final product (Jones, 2000; Naumann, 1982).

2. Man: The Nature of Play

Humans have an intrinsic desire to play, driven by a quest for fun and freedom. Huizinga (1949) describes the play as a voluntary, liberating activity detached from everyday life, existing solely for the joy it provides. While enjoyment can come from work or obligatory tasks, fun emerges from freely chosen activities. The play offers an ordered escape, a way to engage deeply without tangible rewards, which can be instrumental in learning.

3. Flow Theory

Flow theory, introduced by Csikszentmihalyi, explores how people enter a state of immersion when engaging in activities that balance challenge and skill. Research comparing Montessori and traditional teaching shows that when students follow their natural interests, as in Montessori’s approach, they experience greater flow and motivation. Integrating flow into educational design allows learners to lose themselves in a task, enhancing their motivation and deepening their learning experience (Nakamura, 2009; dos Santos, 2018).

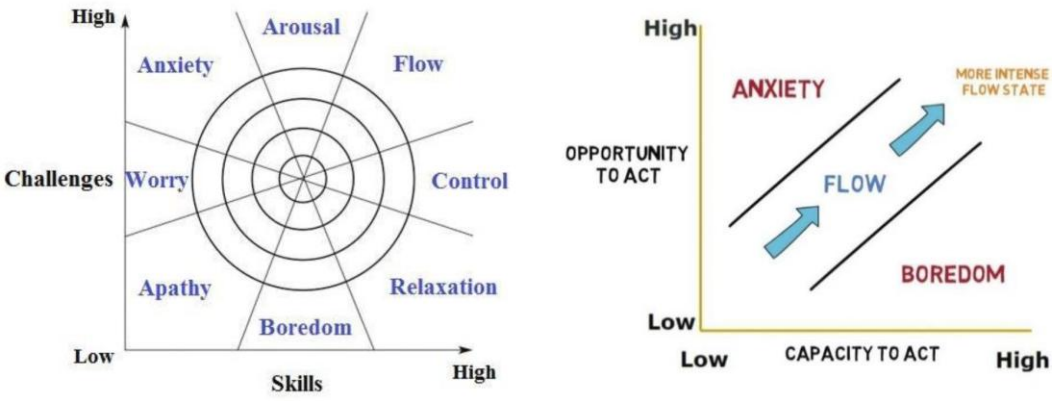

Figure 2. First Model and New Model for Flow State

4. Mathematics and the Art of Proof

Mathematics builds on structured language, accepted principles, and logical reasoning. Although formal proofs are rigorous and systematic, they can often feel inaccessible or intimidating to learners. Informal proofs, on the other hand, are more intuitive and easier to grasp, emphasizing understanding over rigid structure. Educators can make mathematics more approachable by incorporating both formal and informal approaches, balancing precision with accessibility (Hanna, 1991).

5. Games: Purpose and Potential in Education

Games serve as a bridge between work and play, encouraging voluntary participation and engagement. They rely on interaction—whether with objects, other players, or AI—to create a unique space where conventional rules are suspended, allowing players to engage fully. Games bring clear goals, immediate feedback, and subconscious learning, making them powerful educational tools. Successful educational games embody persistence, collaboration, and autonomy, fostering an environment where learning feels natural and enjoyable (Springer, 2009).

6. Teaching Methods

Different teaching methods provide distinct benefits for learning. Passive methods deliver enormous amounts of information quickly but limit interaction. Active methods foster two-way exchanges between teachers and students, while interactive approaches engage students in dialogue with each other and the teacher. Problem-solving, a method valued for encouraging creativity and critical thinking, is considered especially adequate in

mathematics, where understanding is vital. Educators who support problem-solving see it as fostering deep, applied knowledge beyond rote learning (Giorgdze, 2017; Akhter, 2015).

7. Deeper Learning

Learning experiences need to match students' skill levels, reduce unnecessary repetition, and offer diverse ways to engage with content to help them achieve mastery. Strategies like distributed practice, combining visual and auditory materials, and mixing related topics enhance retention and comprehension. Creating a positive learning atmosphere where students feel curious and motivated fosters a love for learning that extends beyond the classroom (Hultberg, 2018; Jensen, 2008).

Together, these theories provide a roadmap for designing educational games that are engaging and effective, offering students a chance to explore, play, and learn meaningfully.

The development journey of "Point Proven" began with simple concepts like card and board games. Although these early prototypes helped test the basic idea, they ultimately failed to bring real analysis concepts to life. Shifting to a digital format was a turning point, allowing more dynamic interactions and enabling mathematical proofs to integrate seamlessly into the gameplay. This transformation made learning more intuitive, allowing players to engage with complex concepts hands-on.

The nature of play, much like mathematics, is inherently detached from material concerns and exists for its own sake. This philosophy led to several game iterations, starting with "Battle of the Azure Seas," aimed at high school students to teach mathematics in an engaging, hybrid approach. Despite incorporating elements like naval warfare and problem-solving, the ambitious goals and complexity presented significant design challenges. The next attempt, "The Geometry of Potion Making," was a board game inspired by a social, debate-style card game. However, issues with open-ended gameplay and the difficulty of judging players' arguments made the experience less effective and engaging.

Learning from these experiences, the team created "Potion Proof: The Grand Elixir," a cooperative card game focused on mathematical proofs. Though more engaging, it needed help to convey the connection to mathematics clearly to players. The final iteration, "Point

Proven," targeted high-achieving, motivated students, adopting a minimalistic, proof-based approach. However, it also faced challenges in balancing engagement with mathematical rigor. Each iteration underscored the difficulty of integrating complex mathematical content into an enjoyable game, demonstrating the need for substantial development time, resources, and expertise to create a polished and practical educational game (Springer, 2009; Huizinga, 1949; II.3 Flow Theory, II.7 Deeper Learning).

The team initially developed "Point Proven" with minimal graphics or color and no guiding hints, aiming to test the game's core concept. The goal was to evaluate its feasibility and appeal by assessing the mechanics of using axioms and theorems to prove conclusions. The drag-and-drop feature introduced a structured approach, limiting players to valid proofs and helping manage choice paralysis by reducing excessive options. Real analysis was chosen as the content foundation because it aligned well with this structured approach.

The initial version faced challenges, such as a need for more explicit engagement mechanics and issues with proof representation. Players initially struggled to understand the gameplay, but engagement improved significantly after receiving brief instructions. Participants began to experiment more creatively and abandoned brute-force tactics. This positive feedback led the project into the polishing phase, although technical challenges remained regarding substitution rules and ensuring logical consistency. Despite these hurdles, the game showed promise for continued development.

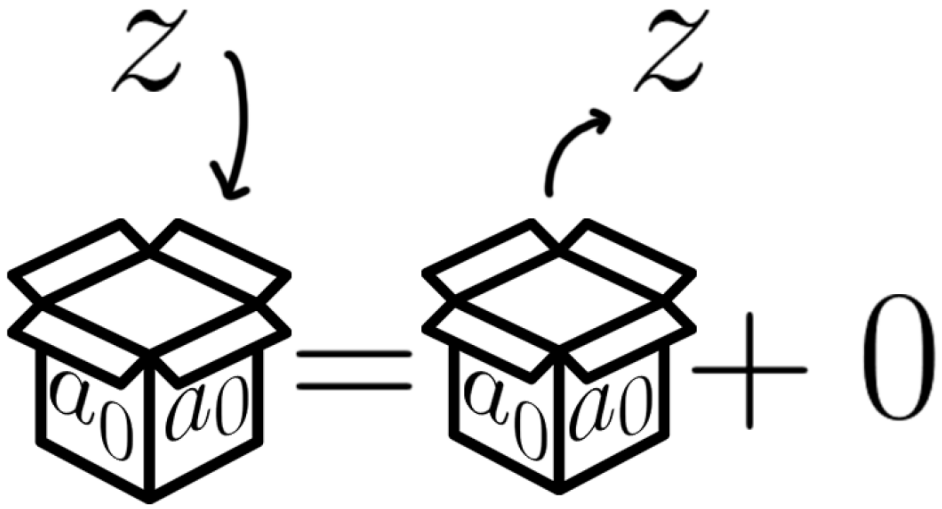

Figure 3. Abstract Example of Substitution (Existence of Zero Elements)

To facilitate understanding, "Point Proven" incorporated a drag-and-drop mechanic for constructing proofs, allowing players to manipulate variables, operators, and statements interactively.

Players progressed through increasingly complex levels, starting with introductory stages to learn basic controls. As they advanced, they encountered more challenging puzzles, fostering deeper comprehension of real analysis and promoting problem-solving and critical thinking skills.

The proof-of-concept for "Point Proven" was developed with no long-term vision and was prepared to be discarded. The team used a brute-force approach for the algorithms, leading to vulnerabilities within the mechanics. They reworked the codebase, added an undo and redo function, polished the substitution process, and introduced real numbers and a level system. Despite technical limitations with grouping statements and managing parentheses, they worked to enhance clarity, ensuring players understood the equations.

The game initially included nine levels, with tutorial and practice sections, but player feedback highlighted confusion and difficulty navigating the interface. To improve clarity, the team added visual cues, reduced text clutter, expanded the workspace, and incorporated interactive features, such as a leaderboard and random number generation (Bartle, 2008; Springer, 2009).

The team conducted a validation session alongside playtesting, involving professionals in educational material, game design, and graphics. The validation evaluated aspects like substance conformity, language, and presentation, with scores for each category averaged and scaled to calculate the final score.

The educational content scored well, especially in language conformity (10.00/10) and overall substance (9.38/10). In contrast, the art and graphics validation highlighted shortcomings, such as UI design (5.00/10), with an overall score of 5.34/10. The gameplay evaluation, focusing on elements like mechanics, engagement, and feedback, received positive scores, especially for overall enjoyment (10.00/10) and challenge level (9.38/10), with an overall score of 8.89/10.

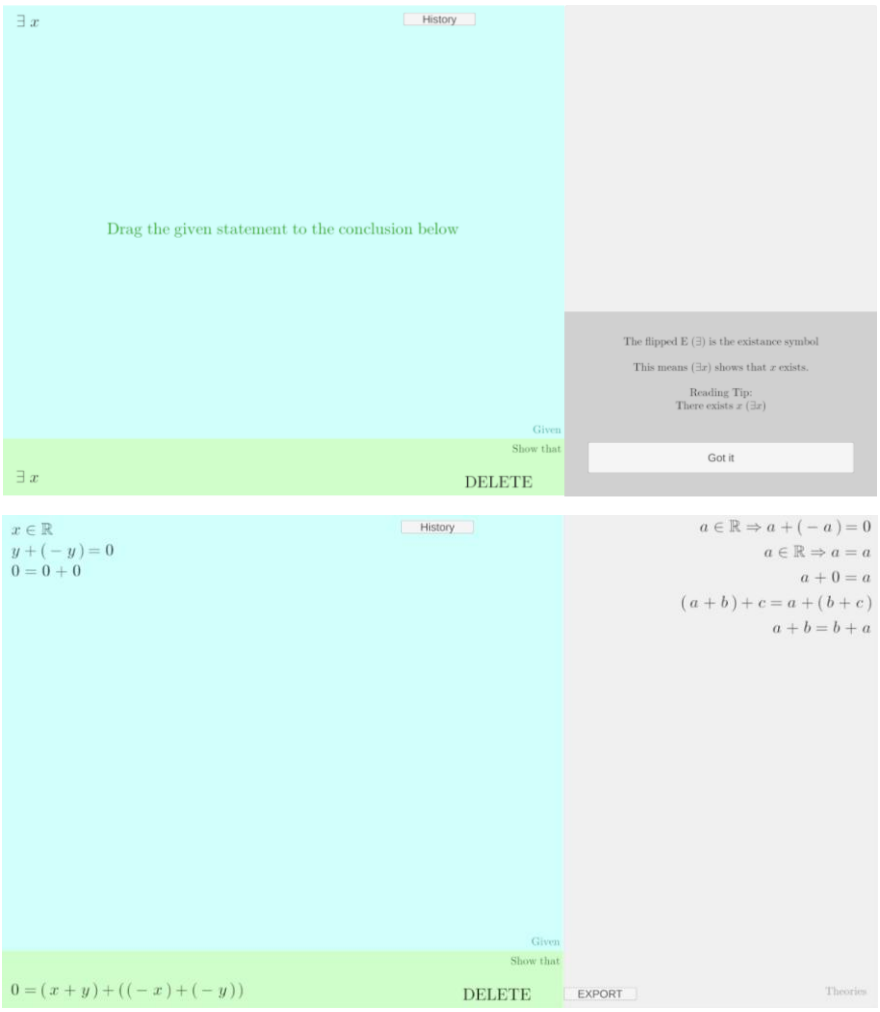

Figure 4. Screenshot of the Game "Point Proven" v1.0

The validation revealed strengths in educational value and overall gameplay satisfaction but significant room for improvement in art, graphics, and mechanics. They expected the low art score, as the primary focus was on education rather than aesthetics, and the abstract nature of real analysis posed challenges for visual representation. Validators tested only introductory levels, indicating potential for further enhancement of these aspects. Overall, the validation confirmed areas of success, particularly in education, while also underscoring the potential for future refinement.

The testing aimed to measure how well gameplay influenced students' understanding of real analysis. Each participant began by taking a pre-test to establish their baseline knowledge, then played the game, and finally took a post-test to gauge improvement. With 100 students participating, these sessions also collected valuable feedback on the game's usability, ability to engage students, and educational impact. This feedback was instrumental in shaping the

final version of "Point Proven," ensuring that the game was educational but also engaging and user-friendly.

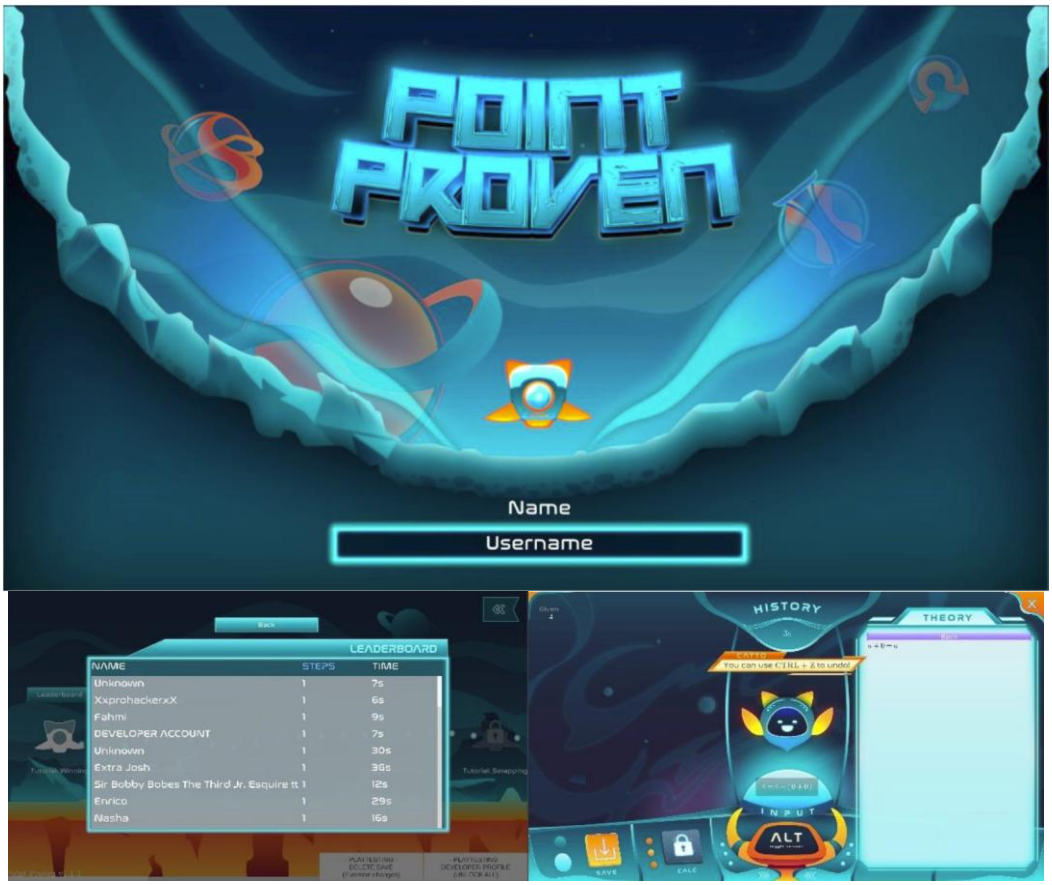

Figure 5. Point Proven v1.1.6

Results

Form Structure

The data analysis involved two main approaches: a pre-and post-test comparison and a difference analysis between initial (pre) and subsequent (post) responses. The first approach assessed feedback from participants who completed the form only once, while the second examined the change in responses before and after playing the game.

Further classification by major showed that 65.9% of participants had a mathematics-related background, including informatics, which aligns with the mathematical content of the playtesting session (see Figure 6). However, many participants found the pre-and post-test questions more engaging than standard textbook questions. This disinterest possibly affected

answer quality, suggesting that future tests should incorporate more captivating questions.

Participants shared varied perspectives on math: around 20 viewed it positively (fun, attractive, functional), seven found it challenging, 6 enjoyed it only when accessible, and 3 disliked real analysis or pure math. The main complaint from 21 participants was that game mechanics were challenging to understand or execute.

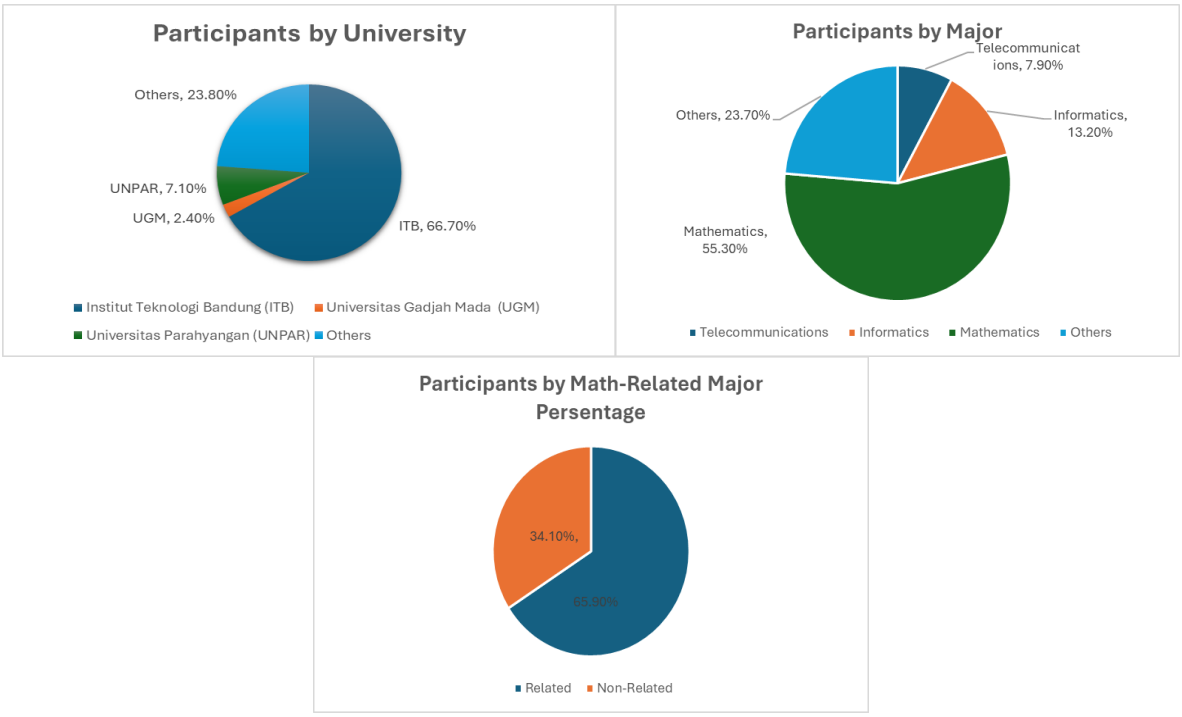

Figure 6. Participant Count by University, Major and Math-Related Major

The feedback indicated that the game effectively catered to real analysis, with some participants seeing its potential academic value. Players noted issues with language and accessibility, but when at least one player successfully navigated the game, they indirectly helped others overcome these accessibility challenges.

The team asked players who participated in the game to provide feedback through questions that explored their experience and opinions in detail. These questions captured players' impressions of the game's visual appeal, enjoyment level, ease of use, and potential educational value. First, the team asked players to rate various aspects on a scale of 1 to 5, including the game's graphics, overall fun, ease of understanding the controls, and relevance

or usefulness.

Beyond ratings, players were encouraged to share specific feedback on what they felt was well-implemented in the game and areas where they saw room for improvement. They also had the opportunity to leave optional comments on the game's potential usefulness and reflections on the playtesting event itself. These insights provided a well-rounded perspective on player engagement, the game's strengths, and any challenges that may impact accessibility or understanding. Table 1 provides an overview of the participant results, revealing that most participants (66.7%) were from ITB, with smaller groups from UNPAR (7.1%) and UGM (2.4%).

Figure 7 highlights vital factors influencing player engagement with "Point Proven," demonstrating the importance of visuals and controls in shaping the gaming experience.

Table 1. Participants' Data Descriptive Analysis

Measurement	Interest	Graphics	Controls	Relevance
Mean	3.80	4.53	3.60	4.21
Std	1.15	0.65	1.24	0.96
Min	1	3	1	1
25%	3	4	3	4
50%	4	5	4	4
75%	5	5	5	5
Max	5	5	5	5

The analysis revealed that visuals and controls significantly shaped player engagement. Graphics strongly correlated with interest (0.60), indicating that visually appealing elements helped capture players' attention. Similarly, controls were crucial for enjoyment, with a 0.65 correlation between ease of use and fun. Players who found the controls intuitive had a more enjoyable experience, whereas those who struggled with them reported lower levels of both enjoyment and engagement.

Interestingly, players with initially low interest in math became more engaged after playing, as reflected by a slight negative correlation (-0.11) between pre- and post-interest. The

correlation indicates that the game succeeded in engaging initially enthusiastic players about mathematics. At the same time, its appeal had less impact on those interested in the subject.

The data also revealed an unexpected link between controls and post-interest, with controls showing a 0.51 correlation to interest and fun displaying a slight negative correlation (-0.2). Rather than enjoyment alone driving engagement, players' interest seemed tied more closely to their sense of competence in solving problems.

This finding suggests that players found mathematics more interesting when they could navigate the game, underscoring the importance of controls in fostering an engaging educational experience. Additionally, math enthusiasts strongly connected relevance to interest and enjoyment, viewing the game as both educationally valuable and personally meaningful.

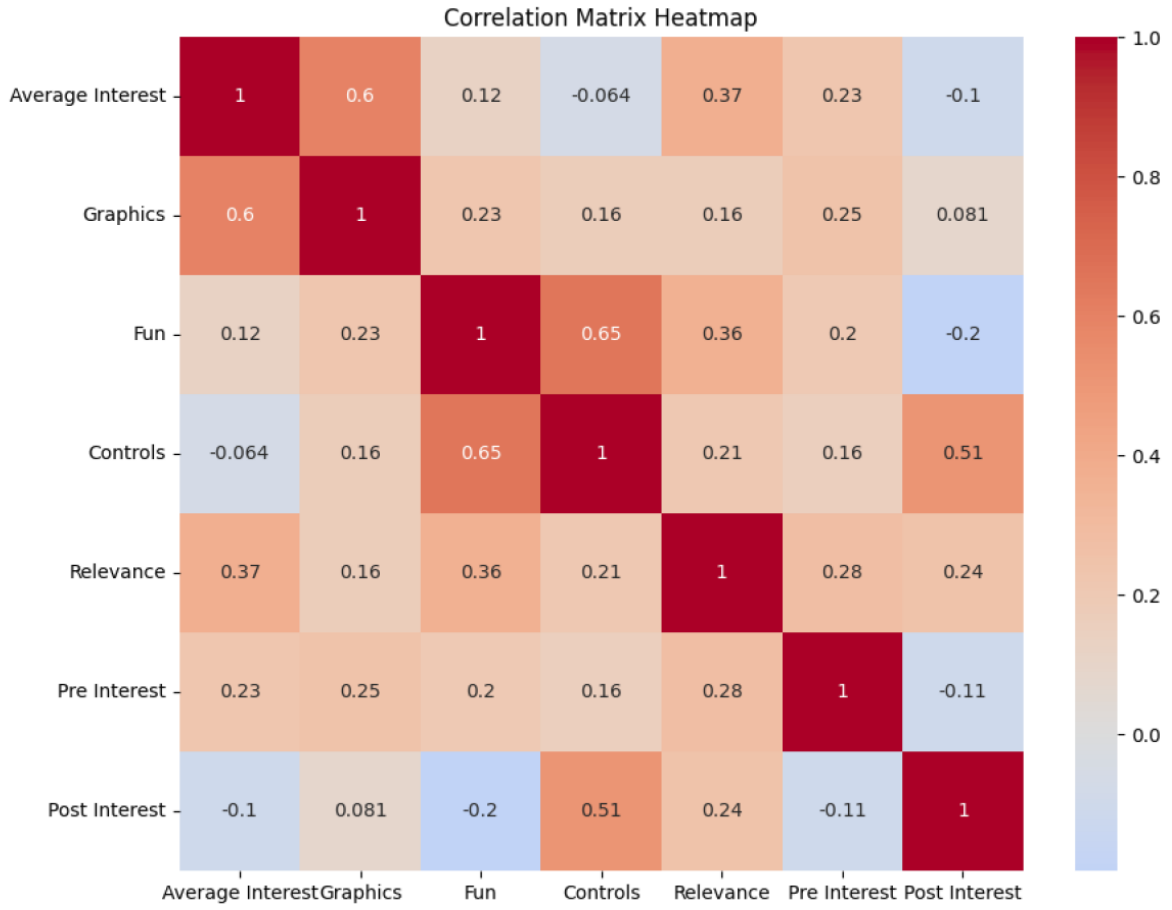

Figure 7. Participants' Data Correlation Heatmap

The scoring for the form tests applied a point-deduction method, deducting one point for each mistake and assigning zeros for blank answers. Each test was worth 50 points, with 10 points allocated per question. Participants' scores showed an average improvement of 0.67 from the pre-test to the post-test, with mean scores increasing from 4.39 to 5.07 (see Table 2). However, the score change was somewhat inconsistent, likely due to participants' varying interest levels and backgrounds in mathematics. Given that game sessions ranged from 30 minutes to 3 hours, participant fatigue may have also contributed to lower scores, as some appeared to duplicate answers across forms, resulting in no change in score (delta = 0).

The descriptive analysis highlights a broad range of scores, from 0 to 10, with a standard deviation of around 3.5 for both tests. Notably, 50% of participants scored around the mid-range (5 to 5.5), while only a few achieved scores close to the maximum. These variations suggest that factors beyond mathematical knowledge, such as engagement level and motivation, likely influenced the results. The following section will delve into in-game metrics collected directly from gameplay to assess player engagement and learning outcomes further.

Table 2. Participants' Score Descriptive Analysis

Measurement	Pre-Test Score	Post-Test Score	Delta Score
Mean	4.39	5.07	0.67
Std	3.53	3.33	2.63
Min	0	0	-3
25%	0	2.75	-0.75
50%	5	5.5	0
75%	7.25	7.75	1.25
Max	9.5	10	10

Game Metric Analysis

The game tracked various metrics, including level completion time and steps taken per level, primarily for leaderboard purposes and analysis. Initially, the goal was to correlate these metrics with form data for a more comprehensive understanding. However, most participants used aliases, making linking game metrics with form responses challenging. Overall, the data

covered 1,238 level completions, with 1,177 completions from the campaign levels. Sixty-two unique players logged 82,892 seconds of playtime (about 23 hours).

Figures 8 and 9 reveal that certain levels were replayed frequently despite the level-locking system, indicating that players often reattempted levels to improve their completion time or approach. The analysis of the first attempts, shown in Figure 10, offers insight into player engagement. Many players dropped off around level A4, which aligns with the recommended ten levels per session. Some players participated out of curiosity rather than interest in mathematics, suggesting varied motivations among participants.

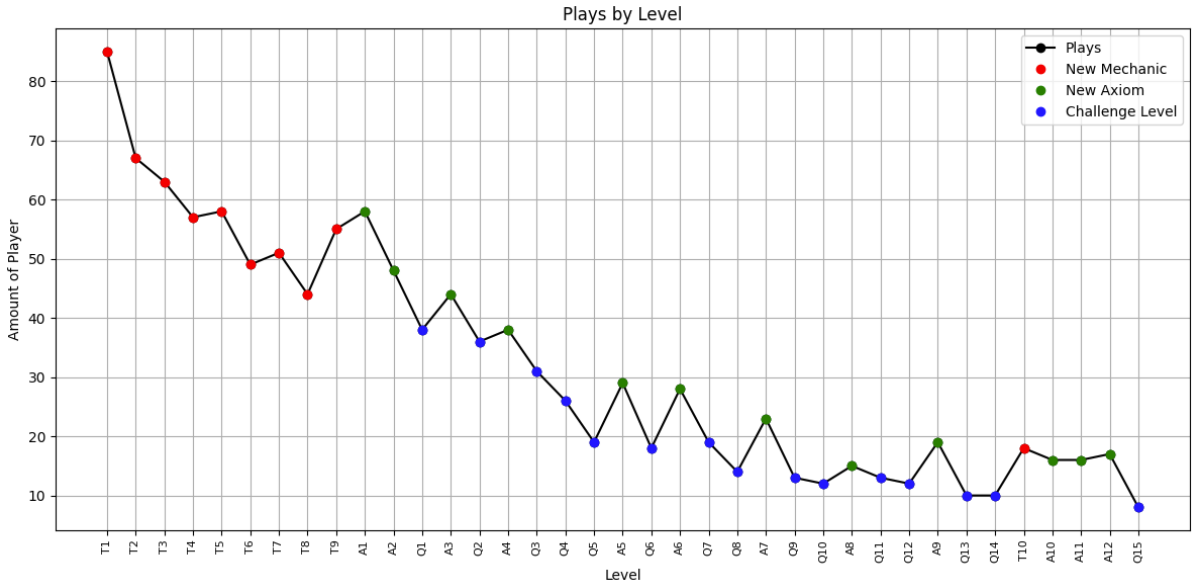

Figure 8. Overall Plays by Level

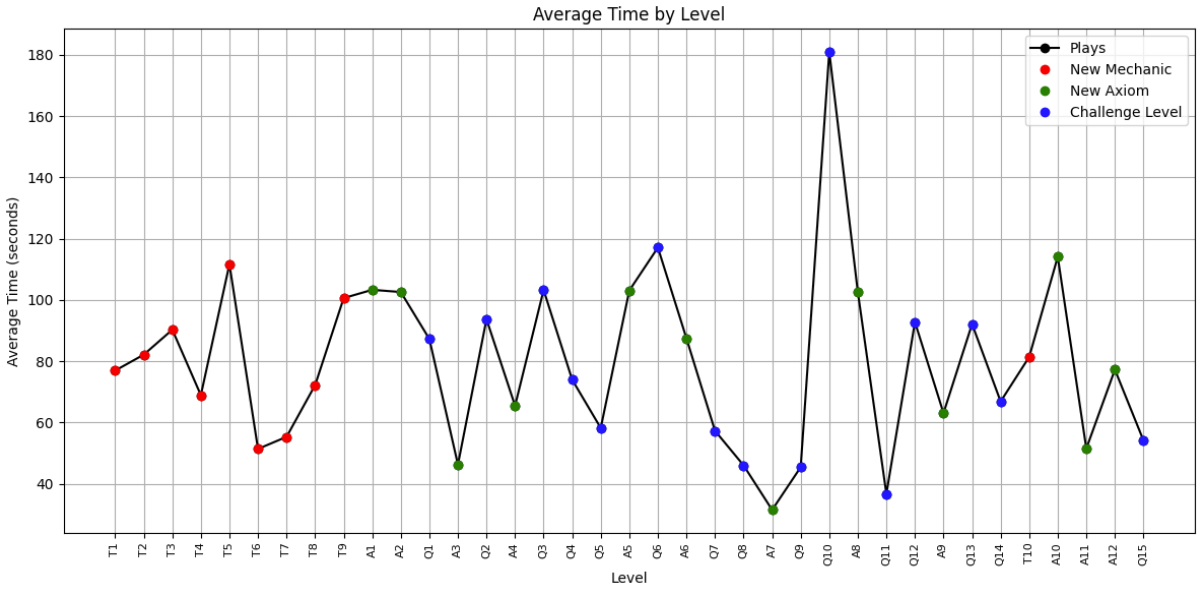

Figure 9. Overall Average Time by Level

Further analysis identified challenging levels where players took excessive time or executed numerous redundant steps. Levels T5 through T9 were particularly difficult, requiring adjustments for a smoother experience. Figure 11 highlights the game's difficulty progression, with a “rollercoaster” curve indicating an intended difficulty variation. However, feedback suggested that some levels were too easy while others were overly challenging. The team designed the final level (Q15) as a “final boss,” but they may need to refine it further if they add new levels to maintain a balanced difficulty curve.

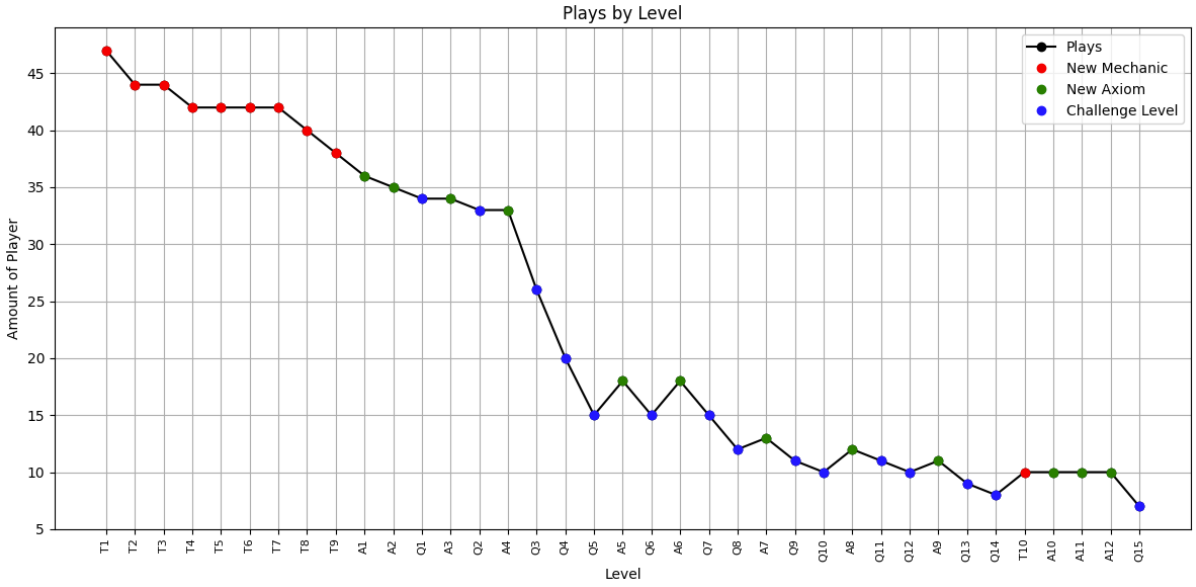

Figure 10. First Attempts Plays by Level

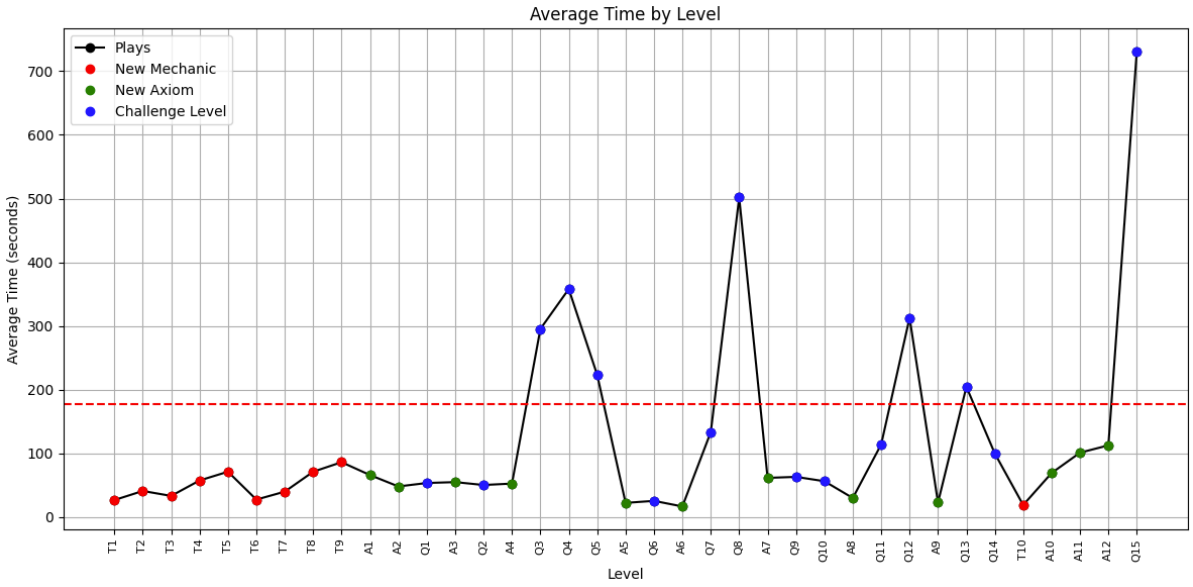

Figure 11. First Attempts Average Time by Level

Observational Data

During the playtesting sessions, testers showed high levels of engagement, likely because developing a game as part of a mathematics thesis was an intriguing and novel concept. A game focused on mathematics and real analysis is rare, which motivated participants to persist through levels despite encountering occasional bugs or glitches. In public testing, the unfamiliarity and challenge of the software led to lively discussions, creating an environment where students helped each other and shared strategies. This collaborative atmosphere resembled an ideal learning environment, as players learned from one another, with the game's structured level progression discouraging shortcuts and promoting a deeper understanding.

The playtests also revealed different types of engagement. Some students who had not initially planned to play became interested after watching others tackle levels, with reactions ranging from amusement at mistakes to admiration for clever solutions. This "spectator effect" encouraged a few onlookers to try the game themselves, which aligns with the research goal of sparking interest in mathematics and real analysis. However, limited available tools on certain levels confused players who could not use previously introduced hypotheses. The confusion caused by limited tools on certain levels, combined with players' frustration during the introductory stages, suggests that adjustments to early mechanics and hints could help maintain engagement and ease players more smoothly into the game's flow.

Discussion

The findings highlight "Point Proven" as a valuable tool for making abstract mathematical topics more engaging, especially for students who initially showed little interest in areas like real analysis. By turning complex proofs into interactive challenges, the game transformed what might have been a daunting learning experience into one that was motivational and engaging. Students who typically struggle with or avoid such topics were more involved and invested, demonstrating the potential of gamified learning to reach diverse learners.

However, the journey was challenging. While the game was generally well-received, some players needed help to navigate the mechanics. This feedback emphasized balancing

accessibility with the educational depth required for real analysis. Some students, particularly those without a strong mathematics background, felt that certain elements needed to be more complex, making the experience less intuitive and potentially hindering engagement. This insight underscores the importance of designing educational games that are rich in content and manageable for a range of learners.

In interpreting feedback, it became clear that intuitive controls and visual guidance enhanced the learning experience. Players consistently highlighted the value of precise, straightforward controls and visually distinct prompts, which helped them grasp the gameplay more easily. The game's educational benefits were most evident for students interested in mathematics. However, an adaptive difficulty system could allow the game to cater to players with various levels of familiarity with real analysis. Such a feature could make the game even more effective by adjusting to each player's learning pace and background, ensuring that all students, regardless of their initial skill level, can benefit from this innovative approach to learning.

Conclusion

In conclusion, this study found that "Point Proven" effectively boosted student engagement and understanding of real analysis concepts. The game's ability to transform abstract mathematics into an interactive experience highlights the potential of gamified tools to complement traditional teaching methods, particularly for subjects that are often challenging to grasp. The success of "Point Proven" demonstrates how gamifying complex mathematical ideas can make them more accessible and enjoyable.

By turning proofs and axioms into dynamic, engaging gameplay, the game opened up a new way for students to approach abstract concepts, suggesting that similar tools could positively impact other areas of mathematics education. Through this approach, students can acquire knowledge and develop a genuine interest in the subject.

The study recommends several improvements for future game versions as we look ahead. Simplifying the controls and making the interface more intuitive could enhance usability, allowing players to navigate the game more quickly. Incorporating adaptive difficulty levels

could further tailor the experience to each student's skill level, making it accessible for both beginners and those more familiar with real analysis. Future research with a more extensive and more diverse group of students could provide further insights. Expanding the game to include community-created levels and advanced topics would broaden its educational scope, making "Point Proven" a more comprehensive and versatile learning tool. Readers interested in exploring the game can access "Point Proven" through:

https://store.steampowered.com/app/3158770/.

References

dos Santos, W. O. (2018). Flow theory to promote learning in educational systems: Is it really relevant? Revista Brasileira de Informática na Educação, 26(2), 29.

Fauzia, M. N. (2024, July 8). Potensi Industri Game Development di Indonesia. (M. R. Yudhistira Azhar Haryono Putra, Editor). Retrieved from Himpunan Mahasiswa Sistem Informasi ITS website: https://arek.its.ac.id/hmsi/2024/07/08/potensi-industri-game-development-di-indonesia/

Hanna, G. (1991). Mathematical proof. In Advanced mathematical thinking (pp. 54-61). Springer.

Huizinga, J. (1949). Homo Ludens. London: Routledge & Kegan Paul.

Hultberg, P. A. (2018). Promoting long-lasting learning through instructional design. Journal of the Scholarship of Teaching and Learning, 18(3).

Jensen, E., & Nickelsen, L. (2008). Deeper learning: 7 powerful strategies for in-depth and longer-lasting learning. Corwin Press.

Jones, T. S. (2000). Rapid prototyping methodology in action: A developmental study. Educational Technology Research and Development, 48(2), 63-80.

Kameke, L. v. (2022, September 14). Number of gamers in Southeast Asia in 2022, by selected country. Retrieved June 23, 2024, from Statista: https://www.statista.com/statistics/1332796/sea-number-of-gamers-by-country/

Giorgdze, M., & Dgebuadze, M. (2017, December). Interactive Teaching Methods: Challenges and Perspectives. IJAEDU- International E-Journal of Advances in Education. https://doi.org/10.18768/ijaedu.370419

Akhter, N., & Anwar, M. (2015, June 1). The perceptions of high school mathematics problem solving teaching methods in mathematics education. Semantic Scholar.

Retrieved June 23, 2024, from https://files.eric.ed.gov/fulltext/EJ1210366.pdf

Nakamura, J., & Csikszentmihalyi, M. (2009). Flow theory and research. In Handbook of Positive Psychology (Vol. 195).

Naumann, J. D. (1982). Prototyping: The new paradigm for systems development. MIS Quarterly, 6(3), 29-44.

OECD. (n.d.). Programme for International Student Assessment (PISA). Retrieved June 6, 2024, from https://www.oecd.org/pisa/

OECD. (n.d.). PISA 2022 results: Indonesia country note. Retrieved June 23, 2024, from https://www.oecd.org/publication/pisa-2022-results/country-notes/indonesia-c2e1ae0e/

Bartle, R. G., & Sherbert, D. R. (2008). Introduction to real analysis (4th ed.). Wiley.

Sanjaya, I. N. (2020, November 28). How does COVID-19 pandemic shape gaming industry in Indonesia? PalArch's Journal of Archaeology of Egypt / Egyptology, 17(6), 10611-10624. Retrieved June 23, 2024, from https://archives.palarch.nl/index.php/jae/article/view/5054

Springer. (2009, January). Games: Purpose and Potential in Education. https://doi.org/10.1007/978-0-387-09775-6

Statistics Indonesia (BPS). (2024, May 2). Total population of age 15 and above by age group, 2022. Retrieved June 23, 2024, from https://www.bps.go.id/en/statistics-table/2/NzE1IzI=/total-population-of-age-15-and-above-by-age-group.html

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Chapter 6 - Revolutionizing Biology Education Through Artificial Intelligence: Pedagogical Strategies, Innovations, and Ethical Frameworks

Dr. Gamze Mercan, MSc./PhD Student Zümrüt Varol Selçuk

Chapter Highlights

- As the digital era advances, Artificial Intelligence (AI) is transforming educational landscapes, particularly within biology education.
- This review paper explores the integration of AI technologies in biology classrooms, focusing on innovative pedagogical strategies, personalized learning environments, and enhanced student engagement.
- The study aims to assess the potential of AI to revolutionize traditional teaching methods while addressing the ethical considerations of its adoption.
- Through an extensive literature review, the paper synthesizes research findings on AI applications in biology education, including case studies of AI-driven tools like intelligent tutoring systems, virtual simulations, and data analysis platforms.
- The review highlights that AI can significantly enrich biology education by providing dynamic, interactive learning experiences and deeper insights into complex biological processes.
- AI-driven analytics allow educators to tailor materials to individual learner needs.
- The study emphasizes the importance of addressing privacy, bias, and ethical concerns associated with AI in education. Integrating AI into biology education offers opportunities to enhance pedagogical approaches and engage students interactively, but it requires comprehensive ethical guidelines and robust frameworks to mitigate potential risks.
- The future of AI in biology education is promising, yet it demands a balanced approach that prioritizes both educational goals and ethical standards.

Introduction

In recent years, the integration of Artificial Intelligence (AI) into various facets of education has ignited a transformative shift, with particularly profound implications in the realm of biology education. This evolution is driven by AI's capacity to tailor educational experiences to individual learner needs, thereby enhancing engagement, understanding, and retention of complex biological concepts (Owan et al., 2023; Wardat et al., 2023). Biology, with its intricate systems and processes, stands to benefit significantly from AI-driven innovations, such as intelligent tutoring systems, virtual labs, and data analysis tools, which offer interactive and personalized learning experiences (Fages, 2020; Hassoun et al., 2021).

The impetus behind this integration is multifaceted, encompassing the desire to address diverse learning preferences, overcome educational barriers, and equip students with the knowledge and skills necessary for a future where biological literacy is increasingly intertwined with technological advancements (Bhardwaj et al., 2022; Chen et al., 2020). The advent of AI in biology education promises a more engaging and effective learning journey, providing educators with tools to deliver content in novel ways that transcend traditional classroom settings (Kim et al., 2018; González-Calatayud et al., 2021).

However, the path to fully realizing AI's potential in biology education is fraught with challenges, including ethical concerns related to data privacy, algorithmic bias, and the potential to widen educational disparities. The deployment of AI in educational contexts necessitates careful consideration of these issues to ensure that AI technologies are used in ways that are ethical, equitable, and aligned with pedagogical goals (Reiss, 2021; Remian, 2019). This paper endeavors to critically examine the intersection of AI and biology education, identifying the opportunities presented by AI for pedagogical innovation and the challenges inherent in its adoption. It aims to shed light on effective strategies for integrating AI into biology teaching and learning, while also addressing the ethical considerations that must inform such efforts (Zhai et al., 2021; Huang et al., 2021).

Guided by an inquiry into the effective integration of AI technologies in biology education, the optimal pedagogical strategies for employing AI in teaching, and the necessary ethical frameworks for its use, this study contributes to the ongoing dialogue on AI's role in

enhancing educational outcomes. Through this exploration, we seek to provide valuable insights for educators, policymakers, and researchers committed to leveraging AI to enrich biology education while navigating the complexities of ethical and practical implementation. By situating AI within the context of biology education, this paper endeavors to chart a course for future investigations and practical applications at the confluence of AI, biology, and education. In doing so, it aspires to advance our understanding of how technology can be harnessed to facilitate educational excellence and innovation.

Justification and Research Objective

The impetus for delving into the integration of Artificial Intelligence (AI) within biology education is underpinned by a convergence of technological innovation and pedagogical need. The advent of AI offers unprecedented opportunities to enhance educational practices, particularly in disciplines that benefit from dynamic and interactive learning tools like biology. The rationale for this study is rooted in the evolving landscape of education, where digital transformation is not just a trend but a necessity to prepare students for a future dominated by technology and data-driven decision-making (Chen et al., 2020; Wardat et al., 2023). AI's potential to customize learning experiences to individual learner profiles presents a promising avenue to address diverse learning needs, thereby improving educational outcomes (Owan et al., 2023; Ahmad et al., 2023).

Moreover, the integration of AI in biology education aligns with the broader educational objectives of fostering critical thinking, enhancing engagement, and promoting deeper understanding of complex subjects. However, despite the promising advantages, the application of AI in educational settings is accompanied by significant ethical, technical, and pedagogical challenges that necessitate a thorough investigation (Reiss, 2021; Remian, 2019). These challenges include concerns about data privacy, algorithmic bias, and the digital divide, which could potentially hinder the equitable access to AI-enhanced education. Therefore, this study is justified by the need to explore both the transformative potential of AI in biology education and the imperative to navigate its associated challenges responsibly. Given the multifaceted nature of AI's integration into biology education and the imperative to address its associated challenges, this study sets forth the following research objectives:

To Evaluate the Current State and Potential of AI Technologies in Enhancing Biology Education

This objective involves an in-depth analysis of existing AI applications in biology teaching and learning, focusing on their impact on student engagement, understanding, and performance. It draws on studies that have documented the implementation of intelligent tutoring systems, virtual labs, and other AI-driven tools in educational contexts (Kim et al., 2018; Fages, 2020).

To Identify Effective Pedagogical Strategies For The Integration of AI in Biology Education

This objective seeks to uncover and analyze methods and approaches that educators can employ to effectively incorporate AI technologies into their teaching practices, thereby maximizing their pedagogical value (González-Calatayud et al., 2021; Zhai et al., 2021).

To Explore Ethical Considerations and Challenges Associated With The Use Of AI in Educational Settings

Central to this objective is the examination of ethical issues related to privacy, data security, bias, and access, aiming to propose guidelines and recommendations for the responsible deployment of AI in education (Reiss, 2021; Remian, 2019). By addressing these objectives, the study aims to contribute valuable insights into the role of AI in biology education, highlighting opportunities for innovation and areas for caution. It endeavors to inform educators, policymakers, and technologists about the potential benefits and limitations of AI, guiding the development of strategies that leverage AI to enhance educational outcomes while upholding ethical standards.

Method

Research Design

Employing a methodical literature review methodology, this study aims to map out the integration of Artificial Intelligence (AI) in the sphere of biology education comprehensively. Following the precedents set by established methodologies in similar reviews (Ulhaq &

Rahmayanti, 2020), this research endeavors to collate, evaluate, and synthesize the existing body of literature to unearth trends, identify gaps, and suggest directions for future research in the application of AI in biology education.

The literature search was systematically conducted across several academic databases, including Web of Science (WoS), SCOPUS, PubMed, IEEE Xplore, ERIC, and Google Scholar, adhering to a strategy designed to capture the breadth and depth of the field. Keywords used in the search were derived from the central themes of the study, including "Artificial Intelligence," "Biology Education," "Pedagogical Strategies," and "Ethical Considerations in AI." The search parameters were confined to materials published between January 2010 and March 2024 ensuring that the review encapsulates the most recent advancements and discussions in the field, as recommended by Chen et al. (2020) and Bhardwaj et al. (2022).

Procedure

The inclusion criteria were tailored to select studies that provide significant insights into AI's role in biology education, including empirical research, theoretical analyses, and review articles that discuss AI-driven pedagogical strategies and ethical considerations (Alpaydin, 2020; Reiss, 2021; Remian, 2019). Exclusion criteria were applied to filter out publications not directly related to the scope of biology education or AI, as well as those lacking in academic rigor or relevance to the research questions at hand. Following a structured approach to data extraction, the study focused on collating information pertinent to AI applications in biology education, pedagogical outcomes, and ethical discussions within the selected literature. This involved summarizing key findings, methodologies, and theoretical contributions to build a coherent narrative around AI's potential and challenges in this educational domain (Zhai et al., 2021; Kim et al., 2018).

Search Results

The initial search yielded a total of 2,500 articles, books, and other works. To refine our selection, we applied specific inclusion and exclusion criteria. The inclusion criteria focused on studies that provided significant insights into AI's role in biology education, including

empirical research, theoretical analyses, and review articles discussing AI-driven pedagogical strategies and ethical considerations. Studies not directly related to biology education or AI, or those lacking academic rigor, were excluded.

Inclusion Process

Screening Titles and Abstracts

We began by screening the titles and abstracts of all 2,500 works to assess their relevance. This step reduced the pool to 600 works.

Full-Text Review

We then conducted a full-text review of these 600 works, evaluating their relevance to our research questions and inclusion criteria. This process further narrowed the selection to 150 studies.

Final Selection

After a thorough review and discussion among the research team, we selected 85 studies that met all inclusion criteria and provided the most relevant and high-quality insights.

Exclusion Process

Throughout the screening and full-text review stages, we excluded 2,415 works. Common reasons for exclusion included a lack of focus on AI or biology education, insufficient academic rigor, or duplication.

Analysis

The thematic analysis was employed to distill the extracted data into coherent themes, which were then critically examined to assess the current landscape and identify areas for future inquiry (González-Calatayud et al., 2021; Zhai et al., 2021). This analytical process allowed for the identification of patterns, discrepancies, and unexplored areas within the literature,

guiding the synthesis of findings in alignment with the study's objectives.

Ensuring Validity and Reliability

To ensure the validity and reliability of our inclusion and exclusion processes, we implemented several measures:

Inter-Rater Reliability

Multiple researchers independently reviewed each work, and any discrepancies were resolved through discussion and consensus.

Standardized Criteria

We developed and adhered to standardized inclusion and exclusion criteria, ensuring consistency in our selection process.

Pilot Testing

We pilot-tested our data extraction form on a sample of studies to ensure it captured all relevant information consistently.

Consensus Building

Regular team meetings were held to discuss and verify the inclusion of studies, ensuring a robust and reliable selection process.By following these rigorous methodologies, we ensured that the studies included in our review were of high quality and directly relevant to our research objectives.

Ethical Considerations

In line with ethical guidelines for literature reviews, all data derived from the selected publications were meticulously cited, ensuring the integrity and transparency of the research

process (Reiss, 2021). The review's focus on ethical considerations in the literature further underscores the importance of navigating AI's integration in education with a conscientious approach to privacy, bias, and equity issues.

Results

The comprehensive literature review conducted on the integration of Artificial Intelligence (AI) in biology education reveals significant advancements, diverse applications, pedagogical strategies, and ethical considerations. The synthesis of the findings is presented through detailed tables, reflecting the depth of AI's impact on the field. These findings are detailed below through carefully constructed tables, each preceded and followed by descriptive narratives to elucidate the context and implications of the synthesized data.

Applications of AI in Biology Education

The application of AI technologies within biology education presents a transformative potential for both teaching and learning processes. Key areas where AI has been implemented include personalized learning experiences through Intelligent Tutoring Systems (ITS), enhanced practical learning via Virtual Laboratories, and the facilitation of complex data analysis with Data Analytics Tools (Table 1).

Table 1. Applications of AI in Biology Education

AI Application	Description	Key References
Intelligent Tutoring Systems (ITS)	Systems providing adaptive, personalized learning experiences through immediate feedback and instructional guidance.	Kim et al., 2018
Virtual Laboratories	Platforms simulating biological experiments, enabling students to explore and learn in a risk-free virtual environment.	Fages, 2020
Data Analytics Tools	Tools assisting in the analysis and interpretation of complex biological datasets for educational purposes.	Hassoun et al., 2021

In the context of advancements delineated in Table 1, the emergence of Intelligent Tutoring Systems (ITS), Virtual Laboratories, and Data Analytics within the sphere of biology education exemplifies a profound paradigm shift. This shift is not merely technological but pedagogical, signaling a move towards a more individualized and accessible educational landscape. Intelligent Tutoring Systems (ITS) in biology education signify a transition towards a customized learning environment. This model supports learners' progression at a pace that is congruent with their individual learning capacities, offering adaptive support mechanisms. This approach accommodates the heterogeneity of student learning preferences, thereby enhancing mastery over complex biological concepts and fostering a higher degree of student engagement.

Virtual Laboratories, conversely, address and mitigate traditional barriers of geography and financial constraints associated with access to experimental biology. By leveraging these platforms, learners from diverse socioeconomic backgrounds are afforded equitable access to high-caliber educational materials. This facilitation of experimental exploration in a simulated setting democratizes the quality of education, ensuring it is not confined to those within specific geographic or financial bounds.

Furthermore, the incorporation of Data Analytics Tools into biology education revolutionizes access to and understanding of complex biological data sets. These tools enable students to engage in in-depth analysis and interpretation of significant data volumes, thereby opening new vistas for inquiry and enhancing comprehension. Mastery of such analytical tools equips learners with critical skills necessary for navigating the data-driven landscape of contemporary biological sciences.

This nuanced approach to integrating AI technologies in biology education not only enriches the educational experience but also aligns with the evolving demands of the 21st-century scientific community.

Pedagogical Strategies Enhanced by AI

The integration of AI into biology education has also led to the development and enhancement of several pedagogical strategies. These strategies leverage AI's capabilities to

foster a more engaging, personalized, and effective learning environment.

Table 2. Pedagogical Strategies Enhanced by AI

Strategy	Description	Key References
Personalized Learning Pathways	AI-driven customization of learning experiences, catering to the individual needs and pace of students.	Owan et al., 2023
Collaborative Curriculum Design	The collaborative use of AI by educators to develop, curate, and optimize educational content and assessments.	González-Calatayud et al., 2021
Interactive and Immersive Learning	Utilization of AI-powered VR and AR for creating deeply engaging and immersive learning experiences in biology.	Zhai et al., 2021

Reflecting upon the applications of artificial intelligence as outlined in Table 2, the advancement and integration of AI in biology education have ushered in significant pedagogical innovations. Among these, Personalized Learning Pathways, Collaborative Curriculum Design, and Interactive and Immersive Learning stand out for their transformative potential. Personalized Learning Pathways epitomize the capability of AI to tailor educational content to the unique learning styles and pace of individual students. By customizing the learning experience, AI not only enhances the efficiency of the educational process but also fosters a deeper engagement with the subject matter. This individualized approach ensures that learners can navigate through content in a manner that maximizes their understanding and retention, making it particularly advantageous for the study of intricate biological concepts.

Collaborative Curriculum Design underscores the collaborative synergy that can be achieved between educators and AI technologies. This partnership facilitates the creation of educational content that is both compelling and informative, tailored to meet the evolving needs of the educational landscape. The dynamic interplay between human insight and AI's data-driven capabilities enables the development of curricula that are not only aligned with educational standards but also resonate with students' interests and learning objectives.

The adoption of Interactive and Immersive Learning techniques signifies a significant advancement in the use of technology to craft authentic and engaging educational experiences. These methodologies leverage the power of AI to simulate real-world scenarios and complex biological systems, providing students with hands-on, experiential learning opportunities. This approach enhances students' understanding of complex subjects by immersing them in realistic simulations, thereby bridging the gap between theoretical knowledge and practical application.

Together, these AI-driven educational strategies herald a new era in biology education, characterized by a greater personalization, collaboration, and engagement. By harnessing the potential of AI, educators are able to create a more interactive, immersive, and effective learning environment that prepares students for the challenges and opportunities of the biological sciences.

Ethical Considerations in AI Integration

The application of AI in education introduces several ethical considerations that must be addressed to ensure responsible use. These considerations include ensuring the privacy and security of student data, mitigating algorithmic bias, and guaranteeing equitable access to AI-enhanced education (Table 3).

Table 3. Ethical Considerations in AI Integration

Ethical Issue	Description	Key References
Data Privacy	The importance of securing student data and maintaining privacy within AI-driven educational tools.	Reiss, 2021
Algorithmic Bias	The need to address and mitigate biases within AI algorithms to prevent perpetuation of inequalities.	Remian, 2019
Accessibility and Equity	The challenge of ensuring all students have equitable access to AI-enhanced educational resources.	Zhai et al., 2021

In alignment with the insights provided in Table 3, the integration of artificial intelligence (AI) in educational tools introduces critical considerations regarding Data Privacy, Algorithmic Bias, and Accessibility and Equity. Each of these aspects plays a fundamental role in shaping a responsible, equitable, and effective AI-enhanced educational landscape. Data Privacy emerges as a paramount concern, necessitating the implementation of robust security protocols and the adoption of transparent data handling practices.

The objective is to cultivate a foundation of trust and safety that reassures all stakeholders of their privacy and data protection within AI educational frameworks. Ensuring the confidentiality and integrity of student and educator data is essential in fostering an environment where AI tools can be utilized without reservations regarding privacy infringements.

Addressing Algorithmic Bias is imperative to ensure that AI's integration into education contributes positively and equitably. It is crucial to acknowledge and mitigate the risk of AI systems inadvertently perpetuating existing social and educational disparities through biased algorithms. By actively working towards bias-free AI algorithms, educators and technologists can pave the way for AI tools that enhance learning experiences and opportunities for all students, irrespective of their background.

Ensuring Accessibility and Equity remains a cornerstone in the deployment of AI in education, aiming to guarantee that these advanced tools benefit all students equally. This commitment involves designing AI technologies that are universally accessible, removing barriers to learning for students with disabilities and those from diverse socio-economic backgrounds. The goal is to leverage AI not only to advance educational outcomes but also to champion a more inclusive and equitable educational ecosystem.

In summary, the conscientious integration of AI in educational settings, as outlined in Table 3, necessitates a comprehensive approach to addressing Data Privacy, Algorithmic Bias, and Accessibility and Equity. By confronting these challenges head-on, the educational community can harness AI's potential to revolutionize learning while ensuring that such innovations are implemented responsibly, equitably, and inclusively.

Discussion

The integration of Artificial Intelligence (AI) into the domain of biology education represents a paradigm shift with the potential to significantly enhance both the efficacy of teaching methodologies and the learning outcomes for students. The transformative impact of AI technologies, as evidenced by the diverse applications highlighted in our study, including Intelligent Tutoring Systems (ITS), Virtual Laboratories, and Data Analytics Tools, underscores a burgeoning frontier in educational innovation (Kim et al., 2018; Fages, 2020; Hassoun et al., 2021).

The Transformative Impact of AI Technologies

The advent of ITS has revolutionized personalized learning, offering adaptive feedback mechanisms that tailor educational experiences to the individual learner's pace and style. This approach not only caters to diverse learner needs but also fosters an environment where students can engage deeply with complex biological concepts at their own pace, thereby enhancing comprehension and retention (Kim et al., 2018). Similarly, Virtual Laboratories provide a practical learning experience that was previously unattainable for many due to logistical and ethical constraints, enabling students to experiment and learn in a controlled, risk-free virtual environment (Fages, 2020).

Data Analytics Tools represent another significant advancement, enabling the analysis of complex biological data sets. These tools facilitate a hands-on approach to scientific inquiry, allowing students to engage with real-world data and contribute to genuine research endeavors from an early stage in their education (Hassoun et al., 2021).

Strategic Enhancements to Pedagogy

The pedagogical landscape is being reshaped by AI, necessitating a strategic reevaluation of teaching methodologies to fully leverage the capabilities of AI technologies. Personalized Learning Pathways, supported by AI, exemplify a shift towards more customized educational content and assessments, enhancing learner engagement and enabling mastery of complex subjects (Owan et al., 2023).

The role of educators in Collaborative Curriculum Design, in conjunction with AI tools, is crucial for developing content that is both scientifically rigorous and pedagogically optimized. This collaboration ensures that AI supplements rather than supplants traditional teaching methods, enriching the learning experience without diminishing the educator's role (Bonnen, Yamins, & Wagner, 2021; González-Calatayud et al., 2021).

Interactive and Immersive Learning experiences, facilitated by VR and AR, offer unprecedented opportunities for students to explore biological systems in a highly engaging and intuitive manner. Such technologies not only enhance the learning experience but also prepare students for future scientific challenges by providing a deep understanding of complex biological phenomena (Zhai et al., 2021; Hornberger, Bewersdorff, & Nerdel, 2023).

Navigating Ethical Considerations

The deployment of AI in educational settings introduces several ethical considerations that must be carefully navigated to ensure the responsible use of these technologies. Concerns regarding Data Privacy and the security of student data underscore the need for stringent ethical guidelines and data protection measures to prevent misuse (Reiss, 2021).

Algorithmic Bias presents a significant challenge, highlighting the importance of ongoing efforts to refine AI tools to ensure they are equitable and inclusive. Addressing these biases is paramount to preventing the perpetuation of existing educational disparities and ensuring that AI serves as a tool for empowerment (Remian, 2019).

Accessibility and Equity in AI-enhanced education are crucial considerations, emphasizing the need to ensure that all students, regardless of socio-economic background, have equal access to these resources. This requires not only technological infrastructure but also the development of universally accessible and culturally relevant content (Zhai et al., 2021).

Conclusions

The integration of AI into biology education offers exciting opportunities for enhancing

pedagogical strategies and student learning outcomes. However, maximizing the potential benefits of AI while addressing its ethical implications requires a concerted effort from educators, policymakers, and technologists. As we continue to explore the vast possibilities presented by AI, it is imperative that we do so with a commitment to equity, inclusivity, and the highest standards of educational excellence.

The analysis underscores the transformative potential of AI in biology education, illustrated by the diversity of applications from intelligent tutoring systems to virtual laboratories. These technologies not only tailor the learning experience to individual needs but also open new avenues for engaging with complex biological concepts through immersive simulations. The pedagogical strategies identified highlight a shift towards more personalized, interactive, and collaborative learning environments, facilitated by AI. However, the integration of these technologies is not without challenges. Ethical considerations, particularly regarding data privacy, algorithmic bias, and accessibility, are pivotal concerns that necessitate vigilant attention and the development of comprehensive guidelines to ensure ethical AI use in educational settings.

In conclusion, while AI presents numerous opportunities to enhance biology education, its successful integration requires a balanced approach that considers pedagogical efficacy and ethical implications. Future research should aim to address the identified gaps, particularly in empirically evaluating the long-term impact of AI applications on learning outcomes and developing strategies to mitigate ethical risks.

Recommendations

Establish Ethical Guidelines

Develop clear ethical standards to guide the use of AI in biology education, focusing on data privacy, algorithmic fairness, and equitable access.

Ensure Inclusivity

Prioritize equal access to AI tools for all students, addressing potential disparities and providing necessary resources to support diverse learning needs.

Provide Educator Training

Offer comprehensive training for educators on integrating AI effectively into their teaching, with an emphasis on enhancing student engagement and learning outcomes.

Encourage Collaboration

Foster interdisciplinary collaboration among educators, technologists, and ethicists to design AI tools that are both pedagogically effective and ethically sound.

Evaluate Long-Term Impact

Conduct research on the long-term effects of AI in biology education to identify best practices and assess the sustained impact on student learning.

Mitigate Ethical Risks

Implement strategies to address ethical concerns, such as bias and data security, ensuring AI use aligns with educational values and principles.

Adopt a Balanced Approach

Integrate AI thoughtfully, balancing its potential benefits with careful consideration of ethical and pedagogical implications to enhance biology education effectively.

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References

Agathokleous, E., Saitanis, C. J., Fang, C., & Yu, Z. (2023). What does ChatGPT mean for biology and the environment? *Science of The Total Environment, 888*, 1–4. https://www.news-medical.net/news/20230517/What-does-ChatGPT-mean-for-biology-and-the-environment.aspx

Ahmad, K., Iqbal, W., El-Hassan, A., Qadir, J., Benhaddou, D., Ayyash, M., & Al-Fuqaha, A. (2023). Data-driven artificial intelligence in education: A Comprehensive Review. *IEEE Transactions on Learning Technologies*. https://doi.org/10.1109/TLT.2023.3314610

Al Braiki, B., Harous, S., Zaki, N., & Alnajjar, F. (2020). Artificial intelligence in education and assessment methods. *Bulletin of Electrical Engineering and Informatics, 9(5)*, 1998–2007.

Alpaydin, E. (2020). *Introduction to machine learning*. MIT press.

Astagisa, R., & Aldiansyah, R. D. (2022). Peran penting artificial intelegent dalam pengembangan metode pembelajaran bagi siswa di Indonesia. *Prosiding*, 228–235.

Bhardwaj, A., Kishore, S., & Pandey, D. K. (2022). Artificial intelligence in biological sciences: A brief overview. *Life, 12*, 19–35.

Bonnen, T., Yamins, D. L., & Wagner, A. D. (2021). When the ventral visual stream is not enough: A deep learning account of medial temporal lobe involvement in perception. *Neuron*, *109*(17), 2755–2766.e6.

Chen, L., Chen, P., & Lin, Z. (2020). Artificial intelligence in education: A review. *IEEE Access, 8*, 75264–75278.

Dhanalakshmi, S., Komalavalli, K., Hemalatha, R., & Kalyani, S. (2021). A study on impact of virtual intelligence among the students of higher education with special reference to Chennai City. *Shanlax International Journal of Education, 9(3)*, 196–200.

du Boulay, B. (2019). Escape from the skinner box: The case for contemporary intelligent learning environments. *British Journal of Educational Technology, 50(6)*, 2902–2919.

Elliott, D., & Soifer, E. (2022). AI technologies, privacy, and security. *Frontiers in Artificial*

Intelligence, 5(April), 1–8.

Fages, F. (2020). Artificial intelligence in biological modelling. In *A Guided Tour of Artificial Intelligence Research: Vol. III*.

González-Calatayud, V., Prendes-Espinosa, P., & Roig-Vila, R. (2021). Artificial intelligence for student assessment: A systematic review. *Applied Sciences (Switzerland), 11(12)*.

Halaweh, M. (2023). ChatGPT in education: Strategies for responsible implementation. *Contemporary Educational Technology, 15(3)*.

Hassoun, S., Jefferson, F., Shi, X., Stucky, B., Wang, J., & Rosa, E. (2021). Artificial intelligence for biology. *Integrative and Comparative Biology, 61(6)*, 2267–2275.

Hornberger, M., Bewersdorff, A., & Nerdel, C. (2023). What do university students know about Artificial Intelligence? Development and validation of an AI literacy test. *Computers and Education: Artificial Intelligence, 5*, 100165.

Huang, J., Saleh, S., & Liu, Y. (2021). A review on artificial intelligence in education. *Academic Journal of Interdisciplinary Studies, 10(3)*, 365–369.

Kim, Y., Soyata, T., & Behnagh, R. F. (2018). Towards emotionally aware AI smart classroom: Current issues and directions for engineering and education. *IEEE Access, 6*, 5308–5331.

Moon, M. K., Jahng, S. G., & Kim, T. Y. (2011). A computer-assisted learning model based on the digital game exponential reward system. *Turkish Online Journal of Educational Technology, 10(1)*, 1–14.

Munawar, S., Toor, S. K., Aslam, M., & Hamid, M. (2018). Move to smart learning environment: Exploratory research of challenges in computer laboratory and design intelligent virtual laboratory for eLearning technology. *Eurasia Journal of Mathematics, Science and Technology Education, 14(5)*, 1645–1662.

Nasution, N. E. A. (2023). Using artificial intelligence to create biology multiple choice questions for higher education. *Agricultural and Environmental Education, 2(1)*, em002.

Owan, V. J., Abang, K. B., Idika, D. O., Etta, E. O., & Bassey, B. A. (2023). Exploring the potential of artificial intelligence tools in educational measurement and assessment. *Eurasia Journal of Mathematics, Science and Technology Education, 19(8)*.

Reiss, M. J. (2021). The use of AI in education: Practicalities and ethical considerations. *London Review of Education, 19(1)*, 1–14.

Remian, D. (2019). Augmenting education: Ethical considerations for incorporating artificial

intelligence in education. *Instructional Design Capstones Collection, 52*.

Sahu, M. (2015). Plagiarism detection using artificial intelligence technique in multiple files. *International Journal of Scientific & Technology Research, 4(8)*, 111–114.

Thomas, J. M., & Young, R. M. (2010). Annie: Automated generation of adaptive learner guidance for fun serious games. *IEEE Transactions on Learning Technologies, 3(4)*, 329–343.

Timms, M. J. (2016). Letting artificial intelligence in education out of the box: Educational cobots and smart classrooms. *International Journal of Artificial Intelligence in Education, 26(2)*, 701–712.

Ulhaq, Z. S., & Rahmayanti, M. (2020). Panduan penulisan skripsi: Literatur review. In *Fakultas Kedokteran dan Ilmu Kesehatan UIN Maulana Malik Ibrahim Malang*. UIN Maulana Malik Ibrahim Malang.

Veselinovska, S. S. (2014). Use the interactive whiteboard in teaching biology. *Technics and Informatics in Education, May*. http://www.ftn.kg.ac.rs/konferencije/tio2014/PDF/510StavrevaVeselinovska.pdf

Wardat, Y., Tashtoush, M. A., AlAli, R., & Jarrah, A. M. (2023). ChatGPT: A revolutionary tool for teaching and learning mathematics. *Eurasia Journal of Mathematics, Science and Technology Education, 19(7)*.

Yang, K.-T., & Wang, T.-H. (2012). Interactive whiteboard: Effective interactive teaching strategy designs for biology teaching. In *E-Learning - Engineering, On-Job Training and Interactive Teaching*. https://doi.org/10.5772/31252

Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education – where are the educators? *International Journal of Educational Technology in Higher Education, 16(1)*.

Zhai, X., Chu, X., Chai, C. S., Jong, M. S. Y., Istenic, A., Spector, M., Liu, J. B., Yuan, J., & Li, Y. (2021). A review of artificial intelligence (AI) in education from 2010 to 2020. *Complexity, 2021*.

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Chapter 7 - First-Year Guide: A Proposal for a Mentorship Program for Students

Mihaela Andrei, Alina Pricopie-Filip

Chapter Highlights

- Due to particular mental processes or due their development, in the initial stage of university, some students experience the feeling of hard work, difficult adaptation or even inadaptability.
- The barrier that rises before them becomes almost impossible to remove.
- The most easily available solution, which comes instantly and is immediately accepted, is school dropout.
- Although regrets for this hasty solution and without a prior analysis of competences do not linger, the characteristic emotional balance determines them to take this inappropriate decision.
- The intervention of qualified factors, like teacher/psychologist/counselor or experimented students, is necessary, indicated and, sometimes, lifesaving.
- The first-year students, helped psychologically, morally and scientifically, will understand and escalate the demands of this stage, the end being a satisfactory one: they will be able to practically adapt to student life.
- Supporting the transition period from pre-university to university is an important factor in reducing school dropout.
- This paper proposes a mentoring program dedicated to 1st year students, with the aim of familiarizing them with the higher education system.

Introduction

The The transition from high school to university marks a significant and often challenging phase in a student's life. For many of them, entering a technical university environment is accompanied by elevated academic expectations, new social dynamics, and increased personal responsibility (Mwale et al., 2024). These demands, coupled with specific mental processes or personal development stages, can create a sense of disorientation and difficulty in adjusting to university life. In extreme cases, this transition poses a psychological barrier that feels insurmountable, pushing some students to prematurely consider dropout as the easiest and most immediate solution. Dropout is a major challenge for many universities around the world, especially for technical faculties, where students often face rigorous academic requirements and a high level of difficulty of study programs. The factors that contribute to this problem are multiple, including academic as well as personal and contextual aspects (Law et al., 2020). In the USA it is a 30% dropouts rate after or within the first year for their student stage (Craft, 2024). In the European Union (EU), according to the statistics created by Eurostat, "in 2023, the rate of young people between the ages of 18 and 24 who leave the education and professional training system prematurely in the European Union is 9.5%". Unfortunately, Romania is at the top of the ranking, with an alarming rate of 16.6% (Eurostat, 2024). This information are presented in Figure 1 (Eurostat, 2024).

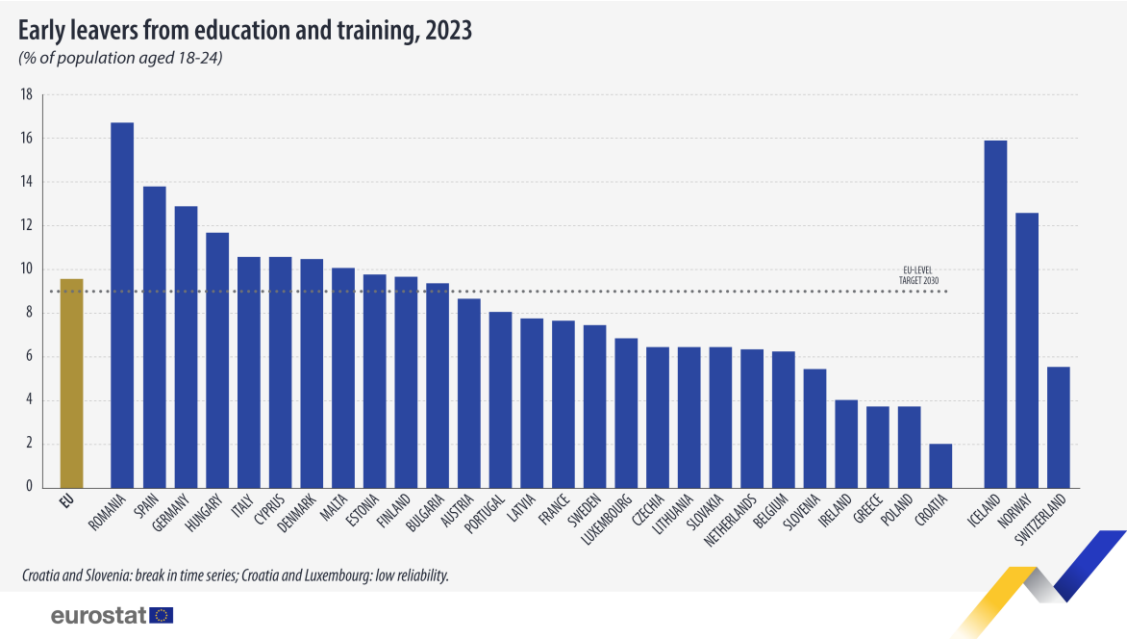


Figure 1. EU dropouts school rate (Eurostat, 2024)

In the last ten years, i.e. from 2013 to 2023, the EU average decreased from 11.8% in 2013 to 9.5% in 2023. However, Romania, had an insignificant evolution in reducing the school dropout rate, remaining at an extremely high level, with 16.6% in 2023, as it can be seen in Figure 2 (Eurostat, 2024). The evolution of Romania from 2013 to 2023 is presented in Figure 3. Data were also taken from Eurostat statistics (Eurostat, 2024), and the graph was made in Matlab. The situation is quite worrying, because all the efforts made until 2021, when the lowest dropout level was measured in our country, were in vain when, after the COVID-19 pandemic, online education returned to the face to face This was the point where the rate started to increase, probably on a psychologically destabilized background. One of the main reasons for dropping out is the high difficulty of the subjects taught in the technical programs, which require advanced analytical and mathematical skills, as well as an autonomous and disciplined learning ability. Students who have graduated from high school may find it difficult to adapt to an intensive academic program based on research and practical applicability (Lapon & Buddington, 2024). In the absence of effective study strategies and solid foundational knowledge, many of them feel the academic pressure very high and end up considering dropping out as the only viable option. This problem is compounded by the lack of psychological support and academic counseling, which are essential for managing the stress and challenges encountered in the early years of study (Lane, 2020).

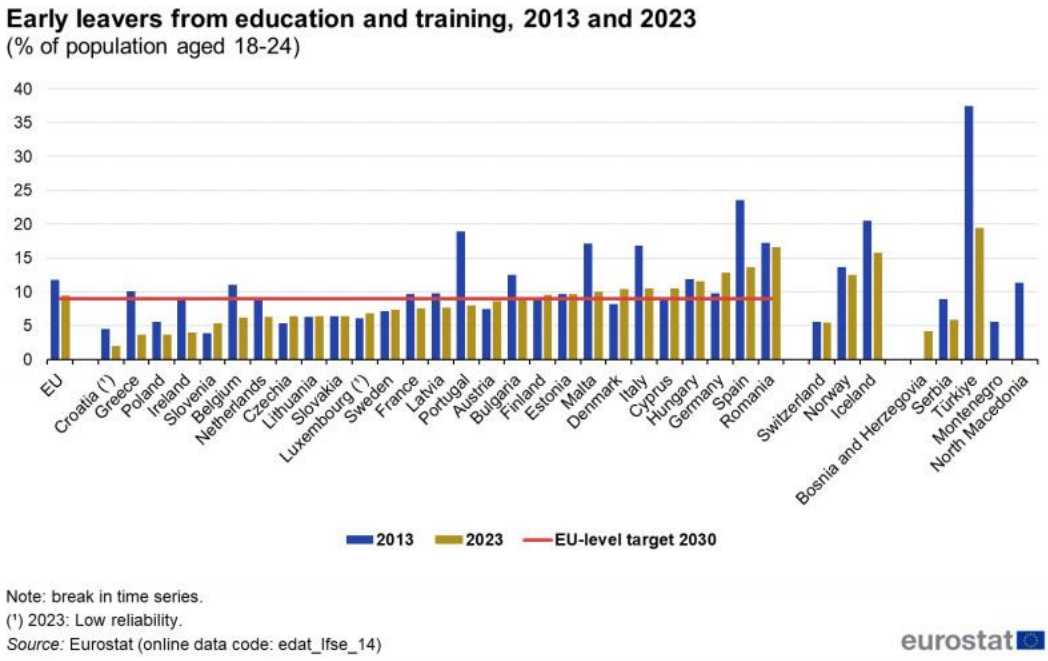


Figure 2. 2013-2023 EU dropouts school rate (Eurostat, 2024)

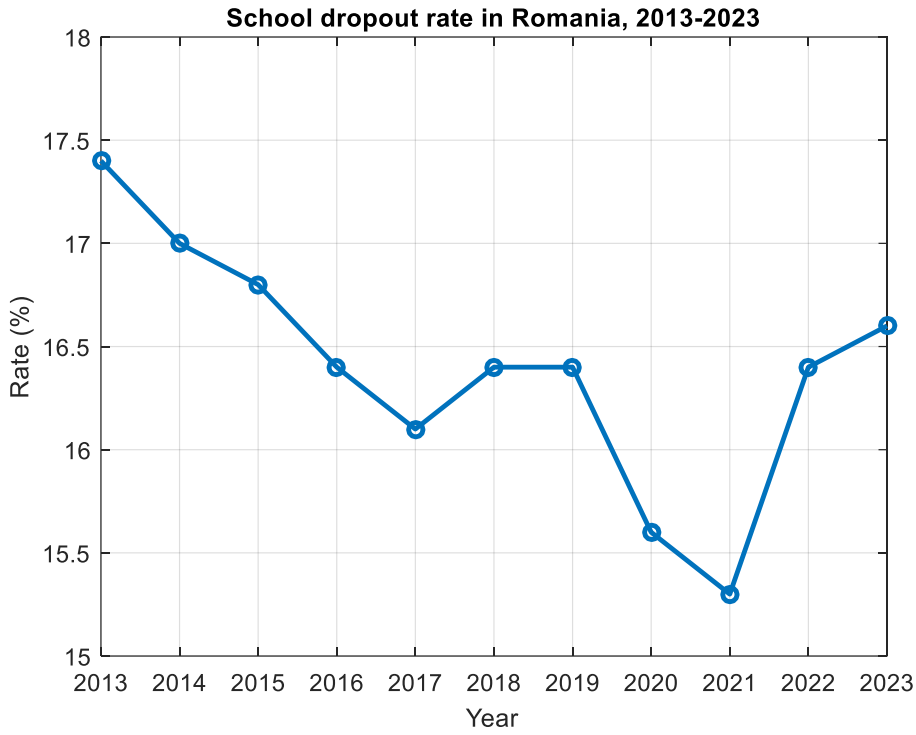


Figure 3. 2013-2023 Dropouts school rates in Romania

Another major factor contributing to the high dropout rate in higher education system is the lack of a sense of belonging and integration in the university community (Duran et al., 2020). Technical students tend to spend a lot of time in individual study activities, which can lead to social isolation and difficulties in building a support network. Studies show that those students who feel integrated into an academic community and have access to support from peers, teachers or mentors are less likely to drop out. Without this support, students may experience a decrease in motivation, academic satisfaction and also isolation (Chin & Kameoka, 2019).

Also, the transition from high school to university has another critical points for students from technical faculties: the organization of the university study forms, the evaluation forms and also the timetables. In high school, they are used to a structured schedule and constant monitoring by teachers, while at university they are required to be much more independent and responsible for their own education. This change can be overwhelming for many of them, especially if they have not been prepared to deal with this new academic reality (Lane, 2020). Lack of support and guidance during this transition period often leads to academic stress, lower performance, and ultimately the decision to drop out.

These challenges of transition are all the more significant for students at technical universities, where the academic demands, the rhythm of work and the complexity of the subjects studied can seem overwhelming to a first-year student. Many of them end up feeling that they cannot adapt, and the solution of dropping out of school becomes attractive, especially in the absence of support resources. The process of university integration is not only a change in the way of learning, but also a profound adaptation to a new lifestyle, new relationships and greater personal autonomy. Without a well-structured support system, this change can be perceived as an insurmountable obstacle, negatively affecting both students' mental health and academic performance.

Studies show that a well-organized mentoring program can significantly facilitate students' adaptation to the university environment. Mentors, whether teachers, counselors, or experienced peers, can provide personalized support that meets each student's unique needs. Through regular interactions and open dialogue, mentors can help students better understand academic demands, manage their emotions, and build a sense of belonging and safety in the university environment (Capstick et al., 2019; Cutillas et al., 2023; Tinoco-Giraldo et al., 2020). The mentoring program proposed in this paper aims not only to reduce the dropout rate, but also to create a more satisfying university experience and form a solid foundation for the academic and personal development of first-year students. They can benefit from the experienced mentors support, including teachers and students from advanced years of study. The program purpose is to help newly admitted students familiarize themselves with the higher education system, facilitate their transition from pre-university and adaptation to the learning/organization/assessment style, etc., basically settling into student life. Supporting the transition period from pre-university to university is an important factor in reducing school dropout. In addition, the academic performances were improved and also the participation on extracurricular activities.

Mentoring activity

What is mentoring?

A simple definition for mentorship is given in (UDOM et al., 2020) as an activity and interaction based on the acceptance of a relationship. It is primarily an activity to introduce the subject, in our case the student, to the knowledge of the science in which he is deficient

and to his self-identity. Second, it is an interaction between a competent person, called a mentor, and the student with learning support needs, called a mentee. The mentor comes to the mentored student with the intention of carrying out the helping activity through which the mentee can develop only if he accepts the proposed mentoring relationship. Both mentor and mentee need to gain the trust of the other, which is the type of relationship this process can work on.

The first-year students faced with challenges like:

- adapting to university timetables and requirements: many students find it difficult to adapt to a much more autonomous educational system with higher academic requirements than in high school. The university imposes a different approach, where students must manage their own time for individual study, learn research methods, and actively participate in seminars and labs.
- time management and exam pressure: the transition from an organized high school schedule to a more flexible but busy one can create confusion and stress. Students must strike a balance between study, projects, and extracurricular activities, all of which influence their academic and emotional performance.
- social integration: many students face difficulties in making new friends, especially if they move to new cities and leave their high school friend group behind. This social isolation can lead to anxiety and even the intention to drop out.
- mental health and emotional stress: academic stress and social isolation often contribute to mental health problems such as anxiety and depression, which can affect academic performance and motivation to continue studying.

These challenges underline the need for a well-structured mentorship program that supports students in adapting to university life and contributes to their academic success. Practically, it is a process of guidance provided by experienced people such teachers, psychologists and other students with some experience (from the greater years of study).

Types of mentoring

Mentoring is a complex activity, taking place in several directions:

- along the lines of counseling the student, to help him set clear and achievable personal development goals and fight for their fulfillment;
- psychologically, in order to give the student the determination to overcome the limits he has and considers that he cannot in any way cross them, based on the crisis resolution models he is in, to find his own way of development;
- on didactic line, for the clarification of misunderstood notions, which are not intuited by the scientific substratum on which they are built or contain knowledge that was not thoroughly acquired at the time;
- pedagogically, for educating and training the student.

Considering the above-mentioned aspects, we can make a classification of the mentorship programs in educational field (Mullen & Klimaitis, 2021):

a) Academic mentoring - aimed at improving students' educational performance and their integration into the university academic environment. This type of mentoring includes learning support, developing effective study techniques, time management, and referrals to additional educational resources. Academic mentors help students to understand course requirements, familiarize themselves with assessment styles, and set academic goals. This type of mentoring is essential for first-year students who need to adapt to a more autonomous learning style and increased workload specific to higher education.

b) Social Mentoring: supports students in the process of integration into the university community and provides them with emotional support. In this type of mentoring, the focus is on creating a support network and developing interpersonal relationships. Social mentors help students navigate the social aspects of university life, form friendships and get involved in extracurricular activities, which contribute to a sense of belonging and reduce feelings of isolation. In addition, mentors provide a safe space where students can discuss the social and cultural challenges they encounter, thus contributing to an easier adjustment.

c) Psychological mentoring: although it sometimes intersects with social mentoring, is focused on counseling and managing the stress and anxiety that may arise during studies. Mentors with training in counseling psychology can provide guidance for students to cope with academic pressure and develop strategies to maintain emotional balance. In cases where

mentors notice significant problems, they can refer students to specialized professionals such as university counselors or psychologists. Psychological mentoring is essential for preventing burnout and improving the mental well-being of students, especially in the first years of college.

d) Professional Mentoring: oriented towards career development and preparation for the professional future. This type of mentoring helps students to explore their professional interests, define their career goals and acquire skills needed for the job market. Professional mentors can provide information about field requirements, internship or volunteer opportunities, and how to build a resume or prepare for interviews. Mentors can also provide students with access to professional networks and networking events, thus creating a bridge between academic life and future careers.

Method

Description of the proposed mentorship program

Objectives

The main objective of the proposed mentorship program was to support the first-year students in their transition from preuniversity to higher education system and to reduce the school dropout rate. From it, we cand derive some secondary objectives, such us: developing time management skill, creating a sense of belonging, improving academic performances, providing emotional support and advising on stress management. All these aspects which outlines the mentoring program can be summarized in Figure 4.

Figure 4. Mentoring objectives

Structure

The mentorship program structure can include one-to-one sessions, group meetings and joint activities, each with a specific role in supporting first-year students with different needs (Hobson & Taylor, 2020).

1. one-to-one sessions are essential to provide personalized support to each student. These meetings allow the mentors to build a relationship of trust and better understand the individual needs, goals and difficulties of each participant. In these sessions, students can discuss the specific challenges encountered in the adaptation process, be they academic, social or personal. Mentors can also provide guidance and resources adapted to each student, such as study method recommendations, time management techniques, or stress reduction strategies. The frequency of these meetings may be weekly at the beginning of the academic year and may gradually decrease as students become more confident and independent.

2. group meetings: are important for students to learn and interact together. These meetings can be themed and address topics of general interest, such as stress management, study skills development, social integration and career guidance. Group meetings are an opportunity for students to share their experiences, learn from each other and see that they are not the only ones experiencing difficulties. In addition, the group can function as a support system where students can encourage each other and form social bonds. Group meetings can be held monthly or bi-monthly and may be facilitated by mentors or an educational advisor who can facilitate discussions and provide useful information.

3. joint/general activities: create a community and help students integrate more easily into the university environment. These activities may include workshops, training sessions, social outings, trips or volunteer activities. Co-curricular activities help develop informal relationships and help students connect with peers and mentors in a relaxed, non-academic environment. Examples of common activities are: thematic workshops (e.g.: development of presentation skills, teamwork, preparation for exams), social activities (eg: dinners, picnics, team game sessions), networking events (eg: meetings with graduates or industry professionals), volunteer activities – which give students the opportunity to contribute to the community and develop interpersonal skills. This type of program is proposed in this paper.

4. online groups: a modern mentoring program may also include an online component to facilitate access to resources and communication between sessions. Social media discussion groups, chats or forums can provide an ongoing support platform where students can ask questions, share experiences and get quick answers. Mentors can use these platforms to share educational resources, learning materials or announcements about upcoming joint activities.

In this paper, we proposed a program based on regular meetings. The common sessions are programed in 7 weeks from 14, plus 2 weeks outside this interval: the first meeting in the preliminary week of the semester and one after the exam session. The calendar of activities is presented in the Implementation section.

Activities

Some of activities proposed within the mentorship program are presented in the following paragraphs and can be divided into 4 categories:

a) For intellectual development:
• knowledge tests, thinking tests, judgment tests, reasoning tests, memory tests - to list vulnerabilities and, above all, to identify the level of these intellectual processes, at the start of the mentoring action and at the end of the mentoring;
• activities to influence and develop these intellectual processes: exercises, problems, creations, drawings, analyses, syntheses, comparisons, discussions, brainstorming, etc.;
• tutoring activities, remedial courses...
• the presentation of model success stories.

b) For professional development:
• tests to identify the skills needed for the profession for which this study program began, in order to validate the option for this faculty profile;
• presentation of the steps to follow to acquire the skills required by the practice the profession he opted for;
O illustrating the beauty of the respective profession, as well as its importance for the national economy;
O exercises to obtain the skills necessary to practice the respective profession.

c) To facilitate integration into university education:

• dialogue with deserving fellow students from the same year and from other years, especially with those in the final year;

• information on the performances obtained by persistent colleagues, focusing on their need to study and absorb the knowledge taught;

• participation in the dialogue organized with these model students;

• engaging in joint actions to borrow from cognitive, moral, volitional and work experience;

• accountability activities within the fulfillment of joint projects with all group or year colleagues.

d) For psychological support:

• activities simulating barriers, limits, difficulties and creating the psychological training framework to overcome them by identifying the solutions and the potential available to the mentoring student;

• initiating discussions about school and life stories in which there is a lack of will, of the belief that the person can do anything if they want, of the belief that you hit it hard if you easily deal with giving up, etc.;

• the valorization of school and life stories that offer models of valorization of will, conviction, moving forward, consonant with the objective of preventing the school dropout of the student in question;

• identifying psychological problems and finding solutions to solve them. In this case, there can be group therapy or individual sessions.

Target group

The target group of the mentoring program is mainly composed of first-year students who are at the beginning of their university career and who need support to adapt to the demands and particularities of the academic environment.

Characteristics of the target group:

a) Age and Educational Experience: Most first-year students are aged between 18 and 20 and generally come from the pre-university system. They are at the beginning of

university life and have little experience in managing an autonomous, complex and diversified educational program typical of technical faculties.

b) The challenges of academic adaptation: Students at technical universities usually face specific challenges due to the high demands of their study programs. The curriculum is often busy, with many complex subjects that require a fast pace of learning and the ability to adapt to new teaching and assessment methods. These students frequently experience difficulty managing time, developing effective study methods, and preparing for more rigorous academic assessments than high school.

c) The challenges of social adaptation: For many students, the transition to college means moving to a new city and separating from family and close friends. Adapting to a new social network, forming relationships with colleagues, and navigating a new cultural environment can be overwhelming. First-year students may feel anxious or insecure, especially if they are unable to quickly form a circle of support within the university. This aspect of adjustment is critical to their emotional well-being and their academic success.

d) The need for psychological support. At the beginning of university life, many students experience stress and anxiety. Academic pressures, combining personal and study responsibilities and significant changes in their personal lives can lead to high levels of stress. Some students may also experience self-confidence issues, feelings of not being prepared enough for college, or even a fear of failure. This emotional vulnerability makes psychological support important during the first months of study.

e) Professional Interests and Goals. Most first-year students are still in the phase of exploring professional interests and do not have a clear picture of their future career. They need guidance to understand the opportunities offered by technical college, to identify areas in which they would fit, and to set career goals. Mentors can play a critical role in clarifying career options and guiding students in shaping a career path.

f) Cultural and Educational Diversity. The target group may include students from diverse social, cultural and economic backgrounds, with different levels of preparation and expectations related to higher education. This diversity can be a source of enrichment, but

also a factor of difficulty, especially for students who feel isolated or overwhelmed by cultural differences.

Mentors

Student mentors and faculty tutors are responsible for guidance and support activities. Tutors are teaching staff and mentors are students from older years selected by interview, giving their younger peers a practical perspective. In addition, there are other persons, like coaches or psychologists, who are involved in this program. They are named mentors. To be effective, a mentor must have certain qualities that help him provide adequate support and inspire students:

• Empathy: The ability to understand and feel students' concerns and difficulties is essential. An empathetic mentor can create a safe and open environment for discussion and problem solving.

• Communication skills: Clear and open communication is vital to building a trusting relationship. The mentor must be able to explain difficult concepts and answer questions patiently.

• Availability and accountability: The mentor must be accessible and dedicated to their role, giving students time and support when they need it. An engaged mentor takes responsibility for responding promptly and maintaining regular contact.

• Academic knowledge and relevant experience: Understanding the academic system and common difficulties faced by students enables the mentor to provide practical advice and relevant information.

• Active listening skills: A good mentor listens without interrupting and encourages their students to freely express their thoughts and concerns. This allows them to feel heard and understood.

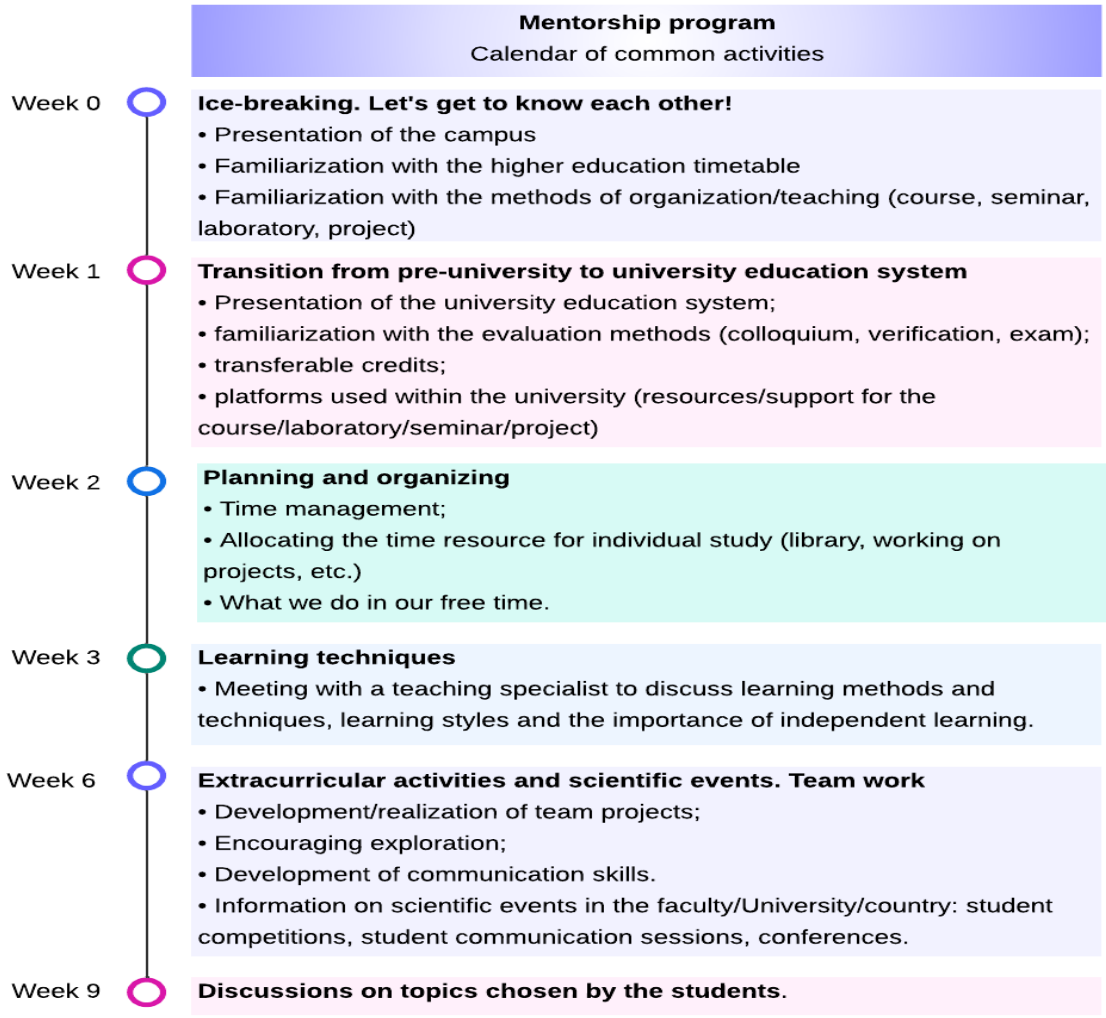
• Patience and calm: A patient mentor can guide students step by step without pressure,

especially when they encounter obstacles or feel discouraged.

• Motivational and positive attitude: The mentor should be a source of inspiration and encouragement, giving students confidence in their own abilities and a positive example to follow.

Implementation. Calendar of activities

In this section we present the calendar of the proposed common activities for first semester of the first year of study. This has 14 weeks, and the proposed mentorship program 7, implemented as follows:



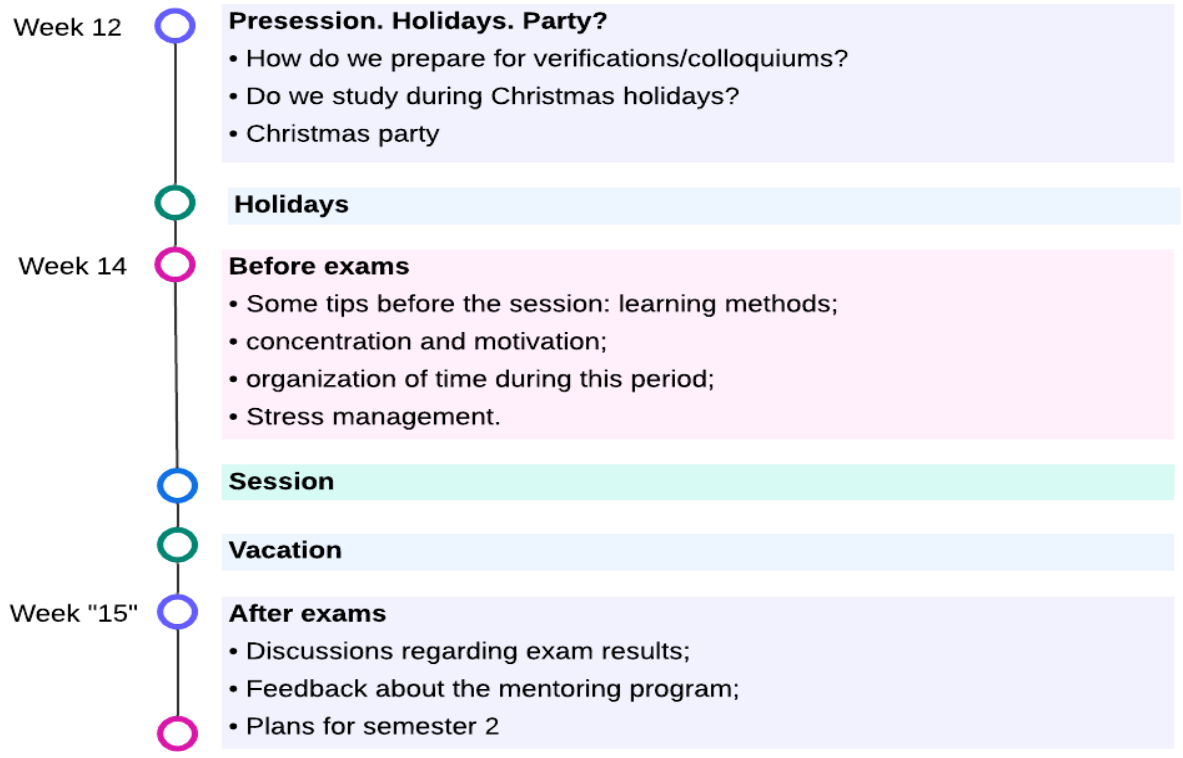


Figure 5. Calendar of activities

Results

Evaluating the success of the mentoring program can be achieved by tracking key indicators that reflect both academic impact and participant satisfaction. We followed 3 of them:

• Reduction of the university dropout rate: one of the clearest signs of the program's effectiveness is the decrease in the dropout rate among first-year students. A decrease in dropout rate was observed.

• Academic performance improvement: academic performance can be another indicator of success, measured by semester averages and credits accumulated by participants. Students have higher grades and pass more exams. An increase in performance may indicate that mentoring helps students adopt more efficient learning methods and organize their time better.

• Participation in extracurricular activities: the number of participants in extracurricular activities (conferences, scientific sessions, competitions) increased. Students developed the

teamwork skills; they made more extracurricular projects and they participated at more students contents.

• The number of social connections: many of the first-year students created new friends among their current colleagues, new connections with university students, even from the higher years of studies. In this way, they can experiment the feeling of belonging and the fact that they have integrated into this system.

Conclusion

The implementation of a mentoring programs can play a decisive role in facilitating the transition to university life by providing students with the necessary resources to understand and solve the academic demands. Well-structured mentoring, focused on both academic support and social integration, can help increase student satisfaction and reduce dropout rates. Thus, mentoring programs not only support students' academic progress, but also their personal development, helping them gain the confidence and resilience needed to successfully complete studies in competitive and demanding technical fields.

The main objective of the proposed program was to support the transition from pre-university to university and reduce school dropout. Besides these, the development of time management skills, the creation of a sense of belonging, the improvement of academic performance, the provision of emotional support and counseling in stress management were also secondary objectives. In addition, the number of extracurricular activities participation increased. The students developed the teamwork skills, they made new friends and they are more relaxed. use numbered headings.

References

Capstick, M. K., Harrell-Williams, L. M., Cockrum, C. D., & West, S. L. (2019). Exploring the Effectiveness of Academic Coaching for Academically At-Risk College Students. *Innovative Higher Education*, *44*(3), 219–231. https://doi.org/10.1007/s10755-019-9459-1

Chin, D., & Kameoka, V. A. (2019). Mentoring Asian American scholars: Stereotypes and cultural values. *American Journal of Orthopsychiatry*, *89*(3), 337–342. https://doi.org/10.1037/ort0000411

Craft, S. (2024). *College Dropout Rates* (ThinkImpact). https://www.thinkimpact.com/college-dropout-rates/

Cutillas, A., Benolirao, E., Camasura, J., Golbin, R., Yamagishi, K., & Ocampo, L. (2023). Does Mentoring Directly Improve Students' Research Skills? Examining the Role of Information Literacy and Competency Development. *Education Sciences*, *13*(7), 694. https://doi.org/10.3390/educsci13070694

Duran, A., Dahl, L. S., Stipeck, C., & Mayhew, M. J. (2020). A Critical Quantitative Analysis of Students' Sense of Belonging: Perspectives on Race, Generation Status, and Collegiate Environments. *Journal of College Student Development*, *61*(2), 133–153. https://doi.org/10.1353/csd.2020.0014

Eurostat. (2024). *Early leavers from education and training*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Early_leavers_from_education_and_training

Hobson, K., & Taylor, Z. W. (2020). Mentoring.ca: Types of mentoring programs featured on Canadian postsecondary education websites. *International Journal of Mentoring and Coaching in Education*, *9*(3), 279–290. https://doi.org/10.1108/IJMCE-09-2019-0089

Lane, S. R. (2020). Addressing the Stressful First Year in College: Could Peer Mentoring Be a Critical Strategy? *Journal of College Student Retention: Research, Theory & Practice*, *22*(3), 481–496. https://doi.org/10.1177/1521025118773319

Lapon, E., & Buddington, L. (2024). The impact of peer mentoring in first-year education students. *International Journal of Mentoring and Coaching in Education*, *13*(1), 73–87. https://doi.org/10.1108/IJMCE-01-2023-0002

Law, D. D., Hales, K., & Busenbark, D. (2020). *Student Success: A Literature Review of Faculty to Student Mentoring*. https://doi.org/10.15142/38X2-N847

Mullen, C. A., & Klimaitis, C. C. (2021). Defining mentoring: A literature review of issues, types, and applications. *Annals of the New York Academy of Sciences*, *1483*(1), 19–35. https://doi.org/10.1111/nyas.14176

Mwale, G., Mwanza, N., & Mweene, D. L. (2024). Students' Adjustment to University Life: Evidence from Lived Experiences. *International Journal of Research and Innovation in Social Science*, *VIII*(X), 1394–1406. https://doi.org/10.47772/IJRISS.2024.8100119

Tinoco-Giraldo, H., Torrecilla Sánchez, E. M., & García-Peñalvo, F. J. (2020). E-Mentoring in Higher Education: A Structured Literature Review and Implications for Future Research. *Sustainability*, *12*(11), 4344. https://doi.org/10.3390/su12114344

Udom, I. D., Okoedıon, E. G., & Okolıe, U. C. (2020). *Impact Of Mentorshıp On Students' Academıc Excellence In Unıversıty Of Benın, Benın Cıty*. *25*(1), 211–228.

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Chapter 8 - Futuristic Digital Technologies and Engineering Competencies

Abid Ali Khan, Tariq Hussain, Mohamed Al Siyabi, Abdullah Al Shibli, Aftab Afzal

Chapter Highlights

- Engineering education's objective is to prepare future graduates and tomorrow's technical workforce.
- They are to control and maintain the crucial resources that are critical for the advancement of technology.
- This rapid advancement is not only reshaping industries at a faster pace but also revolutionizing the development of engineering competencies.
- These competencies are to be developed at different levels of engineering education in higher educational institutions and their engineering career.
- Emerging technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), Quantum Computing, and Virtual Reality (VR) are supporting new approaches to learning and skill-building among engineers.
- These technologies provide hands-on, immersive, and data-driven training experiences that enhance technical knowledge, interdisciplinary collaboration, ethical considerations, and continuous learning.
- The paper examines how these advanced technologies may contribute to core engineering skills development.
- Skills such as problem-solving, system integration, and real-time data analysis may be essential to face the complex challenges of this evolving high-tech, and interconnected world.

Introduction

The In a digital age marked by rapid technological advancement, the engineering profession is faced with a new set of demands and challenges. This rapid technological progress is attributed to the pain suffered by humanity due to the recent pandemic. The challenges of the pandemic brought an opportunity that necessitated humans to react and pave their way through investment in technology. Now this progression requires enhanced competencies, and an adaptable skill set among engineers of the 21st century. In today's contemporary world, engineers must be proficient in technical knowledge and well-equipped to work with cutting-edge technologies shaping the modern industry. Technologies like Artificial Intelligence (AI), Virtual Reality (VR), Digital Twins, the Internet of Things (IoT), and Blockchain are no longer confined to research only. Still, they are fast becoming integral in engineering practice.

Several studies underline the transformative impact that digital technologies have had on engineering education and professional practice, as these advancements require reshaping traditional learning and competency-building processes. One prominent area of influence is Artificial Intelligence (AI), which has introduced personalized learning pathways for engineering students. Research by Baleja, Deng, Bayly and Tapalova, highlights that AI-powered tools can analyze student performance data in real-time, pinpointing areas where students may face challenges and need further support (Baleja, 2024; Deng at al., 2024; Topalova & Zhiyenbayeva, 2022; Bayly-Castaneda et al., 2024) . This tailored feedback mechanism helps students focus on specific weaknesses, allowing for a better grasp of complex subjects and endorsing continuous improvement in both technical and analytical skills. Such customized learning experiences encourage a proactive approach to skill acquisition and equipping engineers with highly relevant competencies mandatory for their specializations and careers. AI is assisting educators and enhancing the quality of education through the use of supportive personalized learning, improving assessment accuracy, and facilitating continuous improvement in curriculum quality.

The use of virtual reality (VR) and augmented reality (AR) technologies has also been widely researched for their capability to create immersive learning environments. According to Ardiny, Magomadov, Yuen and Boyles, VR and AR tools enable students to engage with

intricate systems and models much beyond the conventional methods (Yuen et al, 2011; Magomadov, 2020; Ardiny & Khanmirza, 2018; Boyles, 2017). Execution of risk-free experimentation within simulated environments is mostly convenient for practicing high-stakes procedures, troubleshooting equipment, or working with complex machinery. This convenience has facilitated the simulation of expensive experimentation and hands-on experience in technical fields. The visualization capabilities provided by VR and AR offer a natural grasp of three-dimensional and structural relationships, enhancing students' design thinking and spatial intelligence. This Immersive learning has become handy in facilitating experiential knowledge and preparing engineers to confidently and proficiently handle real-world challenges.

Next on the list of transformative technologies is the Internet of Things (IoT) which is reforming engineering practice by enabling real-time monitoring, data collection, and control in various applications. Several applications found that IoT devices allow engineers to monitor and control complex environments in real time, making this technology especially valuable for fields like construction, manufacturing, and maintenance (Raikar et al., 2018; Mishra et al., 2022; Fernandez & Pallis, 2014). The IoT systems facilitate remote management of equipment and processes, providing continuous insights into operational performance and identifying potential issues before they worsen. This technology not only augments the ability of engineers to manage data-driven systems but also induces an understanding of embedded systems, network integration, and control protocols which are the key competencies in modern engineering.

A common narrative in published literature is the role of digital technologies in encouraging a multidisciplinary approach to engineering education. As noted by Gatto et. al., (2015), and Van Den et. al., (2020) these tools encourage the integration of knowledge from data ethics, science, and systems engineering, proposing to engineers a wider and more versatile skill set (Gatto et. al., 2015; Van Den et. al., 2020). This multidisciplinary approach is increasingly essential, as engineers are required to work across varied fields, work together with professionals from different fields, and consider social, ethical, and environmental factors in their designs. Digital technologies thus not only improve technical skills but also advance ethical reasoning, critical thinking, and adaptability which are the abilities that are vital in the rapidly evolving engineering landscape.

These publications highlight that digital technologies are not mere tools but key systems for skill development and professional readiness. Integration of technologies such as AI, VR, AR, IoT, and multidisciplinary frameworks, etc., digital advancements are preparing engineers for future challenges and opportunities in an interconnected, technology-driven world. The growth of these technologies calls for an adaptable, lifelong learning approach, which is increasingly viewed as critical for engineers who aim to remain relevant and excel in their specializations. The paper examines how these sophisticated technologies have impacted the core engineering competencies model and necessitated the development of essential proficiencies for facing the challenges of the digital future.

Futuristic Digital Technologies

Artificial Intelligence and Machine Learning

These technologies transform engineering education by providing instruments for personalized learning, data analysis, and real-world simulation. Several applications of AI and ML are proving instrumental in the educational and professional landscape of engineering, as they not only facilitate skill acquisition but also encourage a mindset of precision, adaptability, and data-centric thinking. AI and ML are supporting personalized learning, Improving assessment accuracy, and Facilitating continuous improvement in curriculum quality. Together, these instruments contribute to producing engineers who are analytically skilled, technically proficient, and well-prepared for the asks of a technology-driven future.

Automated Learning Systems

AI-driven programs are reshaping how education pursues its objectives of teaching different subjects to students at different levels. Several platforms assisted by AI and ML monitor learners' performance and adapt content delivery to their strengths and weaknesses. For instance, if a student struggles with a specific concept in a subject, the system may recommend additional resources, exercises, or tutorials on that topic. By focusing on areas needing improvement, automated learning pathways enable students to progress more effectively and efficiently. This approach helps students grasp complex subjects faster and

with a more profound understanding. Some typical platforms playing a significant role in the student learning process are as follows:

(a)Dreambox Learning: It focuses on mathematics learning for students through real-time adaptation to student responses. Customized instruction and immediate feedback become available to students and teachers have their dashboards for monitoring progress.

(b)Knewton Alta: It is an accessible and affordable adaptive courseware that provides students with support in higher education courses. It tailors content based on student weaknesses and learning speed and integrates course material to reinforce personalized study paths.

(c)Smart Sparrow: An AI-powered platform that creates adaptive, interactive lessons that are adjusted based on students' responses. Fantastic to ensure that all students understand core concepts and maintain high teaching quality.

(d)CogBooks: Learners benefit from the potential of personalized learning, so CogBooks provides personalized study paths based on performance and engagement that considerably improve course outcomes through support whether courses are taught in a classroom or online environment.

(e)Carnegie Learning MATHia: An AI-driven TutorBot for supporting high school mathematics, which provides detailed feedback and suggestions for teachers. It is believed to produce a diverse range of thinkers, a dynamic approach to assisting students in building math skills, confidence, and excitement.

(f)McGraw Hill ALEKS (Assessment and Learning in Knowledge Spaces): An impactful platform that reports from an embedded assessment for educators. It uses knowledge space theory that assesses and adapts to a learner's knowledge state. It provides a clear roadmap of topics that need more concentration from learners.

(g)Replika: AI chatbot designed to engage students in discussions, assisting in improving their language and conversational skills, specifically in self-paced learning. The platform is

trained by asking the user to answer a series of questions for the creation of a specific neural network.

(h)Edmentum Exact Path: The platform focuses on personalized learning for high school learners. It combines assessment with instructional content and provides personalized learning paths for students.

(i)Cognii: The platform is a leading provider of Artificial Intelligence based educational technologies. It supports higher education, and corporate training markets to assist deliver 21st-century online education with superior learning outcomes and cost efficiency. The product assists students through personalized intelligent tutoring, deeper learning, open response assessments, and pedagogically rich analytics.

Data Analysis Skills

AI applications are also influential in building data analysis expertise among engineers. Engineers working with predictive maintenance systems in industries like automotive or aerospace must analyze widespread datasets for equipment health monitoring. AI tools such as IBM's Watson Analytics activate business-ready data for AI and analytics with Intelligent Cataloging. Microsoft's Azure ML develops and implements an effective cloud strategy. that optimize costs and achieve goals. It is a platform for engineers that identify patterns, analyze huge datasets, and generate items for further actions. This hands-on experience with data advances analytical skills and equips engineers with the skills to optimize processes, understand complex data, and assist data-driven decision-making skills that are vital for modern engineering roles.

AI-Driven Simulation and Modeling

Engineers rely on AI for simulations that mimic real-world environments, providing a safe and immersive platform to refine designs, test theories, and troubleshoot without real-life risks. AI-powered simulation software "SimScale" a computer-aided engineering (CAE) product based on cloud computing enables engineers to model stress tests on buildings, bridges, or other structures to evaluate their strength under different conditions. Similarly,

AI-driven simulation tools to model engine performance, flight paths, and potential system failures, improve problem-solving and decision-making skills in high-stakes environments. These simulations grant engineers the ability to generate quick designs and discover various scenarios, deepening their understanding and developing their competencies for real-world applications.

Virtual Reality (VR) and Augmented Reality (AR)

These technologies are revolutionizing engineering training and skill development by offering immersive, interactive experiences that simulate real-world environments. Applications of VR and AR are becoming essential components of engineering education and practice. Through the creation of immersive, hands-on experiences, these technologies not only benefit engineers develop technical skills but also augment their understanding of three-dimensional visualization, safety protocols, and innovative problem-solving.

These applications bridge the gap between theoretical knowledge and practical proficiency. These technologies create new learning opportunities in fields where hands-on practice and visualization are essential. They assist in preparing engineers to handle complex, high-risk challenges in real life.

Immersive Training Environments

These environments create realistic training settings, allowing engineers to practice troubleshooting procedures, complex machinery operations, and design systems in a controlled, immersive environment. In the automotive industry, companies use VR to train engineers on complex maintenance procedures and assembly line tasks. Engineers can practice these processes in a simulated environment, refining their skills in handling sophisticated machinery or learning the features of vehicle components without the need for physical prototypes.

In aerospace, Boeing uses these applications to teach new employees and technicians before they start working on production lines or aircraft. VR-based training programs have been implemented by different companies that allow engineers to learn aircraft assembly processes

with a high level of precision. This immersive training prepares technical manpower to handle actual machinery confidently, knowing they have already gained experience in a risk-free environment.

Enhanced Visualization

AR technology overlays digital content onto the real world. It is instrumental in improving three-dimensional understanding and design thinking. Engineers in construction or architecture fields can use AR applications like Microsoft's HoloLens or Trimble's XR10 with Mixed Reality capabilities to view 3D models of buildings and infrastructure directly on site. These models assist in visualizing complex designs in their real-world context, identify potential three-dimensional or structural issues, and make mandatory adjustments. Mechanical engineers use AR for digital blueprints that show the internal workings of components, aiding in repair, assembly, and maintenance planning. This enhanced visualization boosts the design process, as engineers make concurrent modifications and better understand three-dimensional associations within their designs.

Risk-Free Experimentation

VR technology allows learners and the technical workforce to practice high-risk tasks, such as repairs and maintenance in hazardous environments, without the linked physical dangers. Industries such as oil and gas employ VR to simulate dangerous situations like equipment malfunctions on offshore oil rigs. Engineers practice the correct procedures for addressing these risks in a virtual setting, enabling them to build critical safety expertise. Similarly, electrical engineers may use VR to simulate high-voltage environments, where they can practice handling equipment safely and confidently without risk. Practicing in these virtual environments raises confidence and augments problem-solving abilities, as engineers can experiment with different approaches and responses to safety challenges.

Internet of Things (IoT)

The Internet of Things (IoT) and Cyber-Physical Systems transform engineering by offering real-time data sources and developing hands-on experience with interconnected devices and

systems. These technologies are important in fields that require complex data management and integration of hardware with software, enabling engineers to develop critical skills for modern industry demands. These applications illustrate how IoT and Cyber-Physical Systems cultivate critical engineering skills. Through real-time monitoring, engineers learn to manage data-driven environments effectively; by working with IoT kits, they gain hands-on experience in network and embedded systems; and through systems integration, they develop the ability to combine hardware and software for unified functionality. As IoT technology becomes more widespread, these skills will be indispensable, preparing engineers to lead innovations in the connected world of the future.

Real-Time Monitoring and Data Collection

IoT facilitates engineers to monitor environments and systems in real-time, which is particularly beneficial in sectors like transportation, manufacturing, and environmental monitoring. In the manufacturing industry, IoT sensors are being used on assembly lines to monitor machine working, detect faults, and predict maintenance demands. Siemens, for instance, has employed IoT-enabled systems that track machinery status, production rates, and component conditions on the workshop floors. Engineers working with these systems gain experience in managing and interpreting real data flows, identifying bottlenecks, and improving operational efficiency. Similarly, in the environmental sector, IoT sensors monitor air and water quality in real time, providing data that engineers use to address pollution issues and optimize sustainable practices. In short, the use of such sensors is becoming common in every household to monitor important environmental parameters.

Hands-On with Smart Systems

Working with IoT kits and devices gives engineers practical experience in programming, smart systems setting up, and troubleshooting. Platforms like Arduino and Raspberry Pi provide engineers with low-cost IoT kits that facilitate learning about data acquisition, network protocols, and embedded systems. Engineering students and professionals can use an Arduino kit to build a smart home system that controls temperature, lighting, and security devices via a central control. This hands-on experience reinforces their understanding of the hardware and software features of smart systems. With this engagement with IoT kits,

engineers develop significant skills in connectivity protocols, sensor integration, and data transmission, which are increasingly essential in a world of interconnected devices. Several commercial solutions through smart devices can be integrated into the centralized hub to control the parameters through smart sensors such as thermostats, locks, doorbells, security cameras, speakers, displays, light bulbs, air-conditioners, home appliances, scales, beds, mobs, and lawn mowers, etc. These devices are penetrating fast into the lives of the common man therefore, awareness of engineers into such technologies is vital for their future careers.

Systems Integration Skills

IoT projects typically involve combining hardware and software components, which facilitates engineers to develop strong system integration and operability competencies. In the healthcare sector, IoT devices like wearable monitors gather health data (e.g., heart rate, oxygen levels) and transmit it to hospital networks where medical professionals can monitor patients remotely. Engineers working on such systems are to ensure that software (data processing and communication protocols) and hardware (sensors and monitors) are fully integrated and compatible for better performance. Automotive companies, such as Tesla, Mercedes, BMW, etc., use IoT systems within their vehicles, where a network of sensors collects data on the environment, vehicle performance, and driver behavior. Engineers in such projects are to ensure perfect communication between hardware sensors and software applications, demonstrating how IoT experience strengthens integration competencies. These autonomous vehicle projects in addition to energy efficiency also acquire benefits such as enhanced safety, reduced traffic congestion, and increased accessibility. Acquisition of such system integration skills will prepare the engineers to handle the challenges of futuristic complex and advanced systems.

Blockchain Technology

Technology is increasingly recognized for its applications in finance with its potential to enhance engineering competencies, particularly in the fields of decentralized system design, data security, and smart contract development. Blockchain has become more integrated into various industries, engineers are gaining vital skills in these areas, preparing them for challenges in sectors like data management, cybersecurity, and legal technology. These

blockchain-based competencies provide engineers with proficiencies that are increasingly valued in today's digital landscape. The combination of decentralized system design, cryptography, and smart contracts prepares engineers to build resilient, secure, and innovative solutions that address the demands of advanced industries. As this technology continues to grow, these competencies will empower engineers to lead advancements in automation, secure data management, and decentralized system modernization around various specializations.

Data Security and Cryptography

Blockchain technology is built on cryptographic principles, providing engineers with practical experience in data security. Industries such as healthcare and supply chain management use blockchain to securely store sensitive information, for instance, patient records or product tracking data, ensuring it remains confidential and secure. MedRec is an example of a blockchain-based platform that securely handles patient records, allowing engineers to work with encryption and access controls to protect patient privacy.

This hands-on experience in cryptography is essential for engineers developing secure systems, as they must understand encryption methods, and data protection protocols to defend against cyber threats. These experiences give engineers an understanding of cryptographic techniques applications for secure transactions and data integrity.

Decentralized System Design

Blockchain's decentralized architecture promotes a shift from centralized databases to distributed systems, enhancing engineers' ability to design fault-tolerant and robust systems. In the energy sector, companies like Power Ledger's blockchain-based peer-to-peer energy trading technology deployment laid the foundation for groundbreaking regulatory change. It allows users to buy and sell renewable energy directly from one another without central authority.

Engineers involved in these projects gain experience in designing and managing decentralized systems, where data and control are distributed across multiple nodes rather

than a single source. Learning of implementation of such decentralized architectures, engineers develop thinking skills, which are beneficial in other sectors such as logistics and telecommunications as well. In systems where distributed networks are becoming more prevalent innovative approaches to data management and synchronization, are the required skills as industries tend to move toward decentralized models.

Smart Contracts

Engineers working with blockchain gain experience with smart contracts where self-executing agreements initiate actions based on predefined conditions. The best smart contract platforms being used in the field are Ethereum, Hyperledger Fabric, MEM crypto, Steller, and Waves. Platforms like Propy use smart contracts to automate transactions, enabling buyers and sellers to transfer property titles instantly once the conditions of a sale are met. Engineers involved in designing such systems must code the contracts in a way that ensures accuracy and compliance with legal and regulatory requirements. Learning to work with smart contracts involves technical and legal knowledge, as engineers must understand programming languages like Solidity (used in Ethereum blockchain) along with legal principles governing contractual agreements. This interdisciplinary approach arms engineers with unique competencies in legal technology, as they learn to bridge the gap between software engineering and regulatory frameworks, essential for industries implementing blockchain for complex, high-stakes transactions.

Digital Twin Technology

It is a high-tech tool for engineers, enabling real-time problem-solving, predictive maintenance, and sophisticated data analytics. Digital Twin Technology thus offers engineers a dynamic platform to develop a range of relevant skills in today's data-centric and efficiency-driven world. The virtual models that replicate physical assets, and digital twins allow engineers to experiment, analyze, and optimize without any impact on the actual system. As industries like manufacturing, healthcare, and urban planning increasingly rely on digital twins, engineers working with this technology develop valuable skills that support efficiency, safety, and performance improvements. These abilities improve the immediate

performance of physical assets but also prepare engineers to innovate solutions that enhance operational efficiency, safety, and resilience across diverse fields.

Real-Time Problem Solving

Digital twins enable engineers to simulate and test solutions on virtual models of physical assets before implementing them in real life. In the aerospace industry, companies like Boeing use digital twins to model aircraft engines and test potential modifications under various conditions. Engineers use these simulations to understand how changes, such as fuel efficiency adjustments or component upgrades, impact performance. Analysis of the digital twin's response to simulated scenarios, optimal solutions to potential issues can be identified without costly and time-consuming physical trials. This problem-solving experience develops engineers' confidence and decision-making abilities in conditions where precision and accuracy are vital.

Predictive Maintenance Skills

Digital twins provide effective insights for predictive maintenance, allowing engineers to predict potential issues before they strike. Companies like General Electric use digital twins to monitor the wind turbine's health and performance. Some other reputed companies using such technologies are Microsoft, Siemens, IBM, Oracle, AVEVA, Bentley Systems, etc. These digital replicas constantly collect and analyze data from sensors embedded in the physical systems, such as vibration levels, temperature, and power output. Analyzing pattering in the data, engineers can identify signs of wear or impending failure, enabling them to schedule maintenance proactively and avoid surprising breakdowns. This predictive approach facilitates optimal maintenance schedules, reduces operational downtime, and extends the life span of assets. Working with digital twins in this way develops engineers' competencies in predictive analytics augmenting their ability to implement preventive strategies, essential for industries where equipment reliability is crucial.

Data Analytics and AI Integration

Evaluating the massive data generated by digital twins strengthens engineers' competencies

in data analytics, specifically when AI is integrated to manage and interpret complex datasets. Smart city development, and digital twins of urban infrastructures, like transport systems and utilities, generate data that can be used for optimum resource allocation, reduce traffic congestion, and improve public services. Engineers working with such digital models can apply AI algorithms to forecast peak traffic times, simulate environmental impacts, or model the impacts of new infrastructure. Integrating AI with digital twin data grants engineers effective experience in handling large datasets, developing predictive models, and identifying relationships that lead to awareness on required steps. Such analytics capabilities are vital as industries gradually rely on data-driven approaches for improved system performance and sustainability.

Robotics and autonomous systems

Robotics and autonomous systems are revolutionizing industries, and the skills acquired by engineers in these areas are diverse and highly pertinent. Engineers engaged with robotics and autonomous systems are skilled with critical capabilities for handling the complexities of real-world applications. Proficiency in mechatronics and control systems ensures that engineers can design and build robots that perform tasks with precision and reliability. Automation demands expertise in multiple areas such as sensor integration, control systems, AI, and real-time problem-solving, providing engineers with a blend of technical and practical skills. Robotic systems are becoming more established in dynamic, real-world environments, engineers are required to build, integrate, and adapt systems to handle complex tasks efficiently and safely. Thus, solving problems in dynamic environments educates engineers to think on their feet, making autonomous systems effective across several industries. These competencies position engineers at the forefront of technological innovation, ready to tackle future challenges in multiple sectors.

Mechatronics and Control Systems

Robotics depends broadly on a combination of mechanical design, electronics, and control theory, establishing the foundation of what is known as mechatronics. In industries, robots are widely used in assembly lines for performing precise and repetitive tasks. Engineers busy with these robotic systems must understand control algorithms that command the robots'

movement and ensure high accuracy.

An example is the Fanuc robot arms, commonly used in manufacturing, which require engineers to integrate control theory principles to manage joint angles and speed precisely. Developing these systems requires engineers to master mechatronics fundamentals, building skills in electrical circuit design, motor control, and feedback mechanisms that are essential across various applications in robotics and automation.

Sensor Integration and AI

Autonomous systems integrate multiple sensors such as cameras, LiDAR, and ultrasonic sensors, enabling robots to observe and interact with the environment quickly. Several industries like agriculture, and autonomous systems like John Deere's precision Ag technology use machine vision to identify and target weeds with weedkiller while avoiding crops. Engineers involved with such systems must be skilled at sensor integration, which combines data from multiple sensors to form an overall understanding of the environment. Additionally, engineers add AI algorithms for tasks like image recognition and decision-making, allowing robots to interpret data from their sensors successfully. This expertise is particularly relevant in applications requiring high precision and situational awareness, such as autonomous vehicles or industrial inspection robots, developing interdisciplinary competencies in high-tech hardware and advanced software.

Problem-solving in Dynamic Environments

Robotics challenges engineers to work in dynamic and often unpredictable settings, where robots must adjust to real-time transformations. Disaster response robots deployed in search and rescue operations require engineers to design systems capable of navigating rough terrain, detecting survivors, and preventing hurdles. Boston Dynamics demonstrates this adaptability; its mission is to imagine and create exceptional robots that enrich people's lives. This work is the next step in the evolution of machines for the repetition, reduction of danger, and physically demanding tasks. Engineers developing such robots are tasked with creating robust control systems that allow the robot to adjust its movement based on variations in the

landscape. Problem-solving in these environments embraces real-time decision-making, where engineers program robots to assess situational data and respond with appropriate actions. This adaptability is instrumental in fields where autonomous systems operate under varying conditions, such as mining, construction, or exploration.

Quantum computing

A multidisciplinary field comprising aspects of computer science, physics, and mathematics utilizing quantum mechanics to solve complex problems faster than on typical computers. It represents a transformative leap in computational power, enabling engineers to solve problems, that are unsolvable with traditional systems. Its unique approach to processing information through quantum bits (qubits) allows for parallel computation on a record scale. Engineers in this field develop competencies in interdisciplinary collaboration, advanced algorithms, and optimization. Engagement with quantum computing develops advanced computational skills necessary for tackling the most challenging problems in modern engineering. They extend a deep understanding of interdisciplinary concepts, enabling collaboration at the intersection of physics, mathematics, and computer science. Unparalleled optimization capabilities of technology prepare engineers to design systems that advance innovation and maximize efficiency. These proficiencies prepare engineers to lead advancements in fields that demand cutting-edge computational power, shaping the future of technology and science.

Advanced Computation Skills

Quantum computing trains engineers with the ability to develop and apply quantum algorithms, enabling them to solve problems involving massive data sets and high complexity. Shor’s algorithm, which can factorize large numbers exponentially faster than classical algorithms, is the foundation of quantum computation. Engineers grasping such algorithms can work on encryption systems that rely on advanced cryptographic techniques, a proficiency direly needed in cybersecurity. Similarly, quantum algorithms like Grover's search algorithm are used to search unsorted databases with an amazing speed, making streamlining data-intensive processes possible in pharma industries for drug discovery and finance for risk analysis.

Interdisciplinary Knowledge

Quantum computing bonds physics, mathematics, and computer science, requiring engineers to develop multidisciplinary expertise. The principles of quantum mechanics reinforce quantum computing's functionality, implying engineers must understand phenomena like superposition and entanglement to design and optimize scientific research instruments. The development of IBM's quantum processors, such as the Eagle processor a 127-qubit quantum processor, highlights how engineers combine physics, mathematics, and computer science knowledge to design hardware, refine quantum error correction methods, and create efficient algorithms. This interdisciplinary approach encourages relationships with experts from diverse fields, preparing engineers for complex, multi-disciplinary projects such as quantum-enhanced machine learning or the development of quantum communication networks.

Optimization Problem-Solving

One of the most significant applications in this domain is solving optimization problems, where multiple variables must be considered to find an efficient solution. Quantum computers address complex logistical challenges such as delivery route optimization for supply chain management. Volkswagen aims to develop an intense understanding of meaningful applications in quantum computing for corporate context. The D-Wave system allows addressing optimization tasks with huge variables at an impressive speed to optimize traffic flow demonstrating how quantum optimization algorithms can manage large-scale systems more effectively than customary approaches. Engineers in such projects gain skills in modeling real-life scenarios, running quantum simulations, and interpreting results to improve system performance. In structural engineering, quantum optimization is also used to identify efficient material configurations for high-strength, lightweight designs, a critical aspect of the aerospace and automotive sectors.

Conclusion

The integration of futuristic digital technologies in engineering is transforming how engineers build and refine their skills. Technologies like AI, VR, and digital twins provide realistic and data-driven learning experiences that strengthen core competencies, while blockchain and

BCI highlight the importance of ethical and interdisciplinary considerations. As engineers work with these tools, they develop not only technical proficiency but also adaptability, critical thinking, and collaborative skills necessary for tackling future industry challenges. The ongoing evolution of these technologies requires a commitment to continuous learning, emphasizing that engineers must be lifelong learners to remain relevant and innovative.

References

Smith, J., & Lee, R. (2023). AI-Driven Personalization in Engineering Education. Journal of Engineering Education, 110(2), 45-57.

Jones, T., & Meyer, P. (2022). The Role of Virtual Reality in Engineering Training. International Journal of Engineering and Technology, 8(3), 321-335.

Nguyen, K., et al. (2021). Real-Time Monitoring in IoT Systems: Implications for Engineering Practice. IEEE Transactions on Industrial Informatics, 17(4), 3456-3465.

Zhang, Y., & Williams, A. (2020). Multidisciplinary Approaches in Engineering Education: Preparing for the Future. Engineering Horizons, 15(1), 92-104.

Brain-Computer Interfaces (BCI)

•Human-Computer Interaction: BCIs require knowledge of how humans and machines communicate, promoting skills in neural engineering and bioinformatics.

•Signal Processing and Data Analysis: BCIs rely on interpreting brain signals, requiring engineers to develop competencies in processing complex biological data.

•Ethical Engineering: BCIs highlight the importance of ethics, as engineers consider privacy, consent, and the social impact of invasive technology.

Robotics and Autonomous Systems

•Mechatronics and Control Systems: Working with robotics develops core skills in control theory, mechanical design, and electronics.

•Sensor Integration and AI: Autonomous systems integrate sensors and AI, fostering interdisciplinary competencies in sensor fusion, machine vision, and intelligent control.

•Problem-Solving in Dynamic Environments: Robotics challenges engineers to solve

problems in real-time and in unpredictable conditions, enhancing adaptability.

Quantum Computing

•Advanced Computation Skills: Engineers develop unique competencies in quantum algorithms, vastly different from traditional computing, preparing them for high-complexity problem-solving.
•Interdisciplinary Knowledge: Quantum computing draws on physics, mathematics, and computer science, requiring engineers to work at the intersection of these fields.
•Exploring Optimization Problems: Quantum computers excel at solving optimization problems, a skill that enhances an engineer's ability to design efficient systems.

How These Technologies Promote Engineering Competencies

•Interdisciplinary Thinking: Most futuristic technologies require a blend of skills across engineering, data science, biology, and social sciences.
•Ethical and Responsible Innovation: Engineers are pushed to consider the social impact of these technologies, developing competencies in ethical reasoning.
•Continuous Learning: Rapid technological advancement fosters a learning mindset, essential for engineers to stay relevant and adaptable.
•Collaboration and Communication: Working with specialists in various fields, engineers develop soft skills crucial for multidisciplinary collaboration.

Leveraging these technologies in training and practical applications helps engineers build the competencies needed for a future driven by complex, interconnected systems.

References

Ardiny, H., & Khanmirza, E. (2018, October). The role of AR and VR technologies in education developments: opportunities and challenges. In 2018 6th rsi international conference on robotics and mechatronics (icrom) (pp. 482-487). IEEE.

Baleja, K. (2024, July). Exploring the Efficacy of Personalized Learning Pathways Utilizing Artificial Intelligence in Education. In EdMedia+ Innovate Learning (pp. 157-161).

Association for the Advancement of Computing in Education (AACE).

Bayly-Castaneda, K., Ramirez-Montoya, M. S., & Morita-Alexander, A. (2024, August). Crafting personalized learning paths with AI for lifelong learning: a systematic literature review. In Frontiers in Education (Vol. 9, p. 1424386). Frontiers Media SA.

Boyles, B. (2017). Virtual reality and augmented reality in education. Center For Teaching Excellence, United States Military Academy, West Point, Ny, 67.

Deng, W., Wang, L., & Deng, X. (2024). Strategies for Optimizing Personalized Learning Pathways with Artificial Intelligence Assistance. International Journal of Advanced Computer Science & Applications, 15(6).

Fernandez, F., & Pallis, G. C. (2014, November). Opportunities and challenges of the Internet of Things for healthcare: Systems engineering perspective. In 2014 4th international conference on wireless mobile communication and healthcare-transforming healthcare through innovations in mobile and wireless technologies (MOBIHEALTH) (pp. 263-266). IEEE.

Gatto, A., Bassoli, E., Denti, L., Iuliano, L., & Minetola, P. (2015). Multi-disciplinary approach in engineering education: learning with additive manufacturing and reverse engineering. Rapid Prototyping Journal, 21(5), 598-603.

Magomadov, V. S. (2020, November). Examining the potential of VR and AR technologies for education. In Journal of Physics: Conference Series (Vol. 1691, No. 1, p. 012160). IOP Publishing.

Mishra, M., Lourenço, P. B., & Ramana, G. V. (2022). Structural health monitoring of civil engineering structures by using the internet of things: A review. Journal of Building Engineering, 48, 103954.

Raikar, M. M., Desai, P., Vijayalakshmi, M., & Narayankar, P. (2018, September). Upsurge of IoT (Internet of Things) in engineering education: A case study. In 2018 International Conference on Advances in Computing, Communications and Informatics (ICACCI) (pp. 191-197). IEEE.

Tapalova, O. O., & Zhiyenbayeva, N. (2022). Artificial intelligence in education: AIEd for personalised learning pathways. Electronic Journal of e-Learning, 20(5), 639-653.

Van den Beemt, A., MacLeod, M., Van der Veen, J., Van de Ven, A., Van Baalen, S., Klaassen, R., & Boon, M. (2020). Interdisciplinary engineering education: A review of vision, teaching, and support. Journal of engineering education, 109(3), 508-555.

Yuen, S. C. Y., Yaoyuneyong, G., & Johnson, E. (2011). Augmented reality: An overview

and five directions for AR in education. Journal of Educational Technology Development and Exchange (JETDE), 4(1), 11.

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