Augmented Reality-Based Mobile Learning: Enhancing Student Spatial Intelligence

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Mobile learning is highly recommended for teachers in implementing virtual learning during the COVID-19 pandemic as a substitute for face-to-face learning. This study aims to provide an overview of the development of Augmented Reality (AR)-based Learning Mediums in improving students' spatial intelligence on the basics of Mapping, Remote Sensing, and Geographic Information Systems in SMA in West Sumatra. The results showed that there was an increase in the spatial ability of students in the Basics of Mapping, Remote Sensing, and Geographic Information Systems in Class X's odd semester using augmented reality-based mobile learning.

Keywords: augmented reality, mobile learning, spatial intelligence

INTRODUCTION

Technological knowledge is related to the knowledge and skills of teachers in integrating and utilizing technological advances and their aspects to support the implementation of learning. The higher education sector has witnessed drastic changes due to new advances in technology including computers and smartphones. As a result, it is necessary to build a strong foundation aided by information communication technology (ICT) where mobile applications can expand learning opportunities (Al-Mashhadani & Al-

Rawe, 2018). Behind technological advances in learning, there are problems in its implementation such as the limitation of students' devices which is the basis for the development of mobile learning. Several studies related to mobile learning, among others, mobile learning is proven to be effective in improving student learning outcomes and interests (Al-Adwan, Al-Madadha, & Zvirzdinaite, 2018). In line with that, the interactive learning process seeks to reduce the gap between students' knowledge and real-life experiences (Chandler & Hwang, 2015). The most well-established model for measuring improvement in learning outcomes is the technology acceptance model, which can predict behavioral intentions in using technology (Sprenger & Schwaninger, 2021). The interactive learning process is supported by technology-based learning tools (Krull & Duart, 2017). It is expected that learning in the classroom and outside the classroom is always optimal with the presence of mobile learning (H. C. Wong, 2014).

Mobile learning has become a popular choice for students due to its familiarity and effectiveness as a learning platform (Vallejo-Correa, Monsalve-Pulido, & Tabares-Betancur, 2021). Studies have shown that mobile learning can increase student engagement in their studies (Dennen & Hao, 2014) and improve learning outcomes (Abbas, Hwang, Ajayi, Mustafa, & Bilal, 2021). The adaptability of academic digital content on academic platforms has also improved through the implementation of recommended systems that can analyze and adapt to the specific learning styles and characteristics of each student (Vallejo-Correa et al., 2021). Mobile learning provides a convenient and personalized approach to education that can benefit both students and educators.

Online learning, supported by a simple and easily accessible time-bound technology framework for the digital community, can significantly improve learning outcomes (Sayibu et al., 2021). Mobile learning combines society, education, and technology in dynamic ways (Traxler, 2007). It is well-suited for assignments, exams, and student learning situations that emphasize community interaction and provide online assessment through MOOCs (Dhawan, 2020). To ensure the proper use and implementation of mobile learning, it is important to thoroughly analyze it from both a pedagogical and technological perspective (Ally & Prieto-Blázquez, 2014; Hofer, Grandgenett, Harris, & ..., 2011) Therefore, mobile learning is highly recommended for teachers as a substitute for face-to-face learning during the COVID-19 pandemic.

The use of mobile learning brings various benefits to fellow students (Rius, Clarisó, & Masip, 2014). The use of mobile devices in learning pays special attention to clarifying factors, techniques, and strategies that enhance the learner experience in using mobile devices (Sophonhiranrak, 2021). Geography learning has content related to reciprocal phenomena between physical (nature) and social. Geographical abilities such as three-dimensional positioning train the mind spatially (Zhang & Wang, 2020). The next challenge in learning geography is delivering very dense and visual content to students during distance learning so that researchers have an idea of using mobile learning combined with augmented reality. Augmented Reality (AR) is an interesting and accessible technological method, which is used to improve understanding in the learning process.

Augmented Reality (AR) technology can facilitate distance learning by enabling students and teachers in different locations to conduct virtual classes using virtual objects and learning materials, and interact with others in a virtual environment (Hakiki, Muchson, Sulistina, & Febriana, 2022). The use of AR has been found to increase student participation and engagement in learning conceptual knowledge (E. Y. W. Wong, Kwong, & Pegrum, 2018). AR technology provides learners with contextual information, which can aid their understanding of the material (Adedokun-Shittu, Ajani, Nuhu, & Shittu, 2020). Additionally, AR and Virtual Reality (VR) can be used to generate ideas for lesson plans for teachers. In outdoor learning environments, AR in 3D can be used to present material in an engaging way, which can increase student interest in learning. The application is designed to include material and quizzes to help students practice and master the material by working on quiz questions.

The COVID-19 pandemic and the increased emphasis on digital skills have necessitated significant changes in the way learning is designed and conducted within schools (Yuan, Wei-Han Tan, Ooi, & Lim, 2021). Online innovation-based learning differs greatly from traditional in-person learning in schools (Rayuwati, 2020) as it involves remote communication between teachers and students, who may be in different locations with varying levels of technological proficiency. However, traditional learning methods, which tend to be teacher-centered, competitive, and lack interaction and collaborative learning activities (Nofrion, Wijayanto, Wilis, & Novio, 2018), may not effectively meet the needs of students who require specific learning competencies in this new online learning environment. Educators need to adapt their teaching methods to better support online learning and the diverse needs of their students during the COVID-19 pandemic.

The problem was found in the field that the students' limitations of learning tools have become problematic themselves. High school students have smartphones with limited capacity, so it is ideal for mobile learning. Digital integration is also important for a 21st-century education, but it is not enough to simply add technology to existing teaching methods. The findings show that relative advantage, complexity, social influence, facilitating conditions, and perceived enjoyment represent key facilitators for mobile learning (Al-Adwan et al., 2018). Technology must be used strategically to benefit students. A lot of learning confuses students by trying to teach them how to use irrelevant programs, websites, and hardware.

Geography is the study of the earth's natural and social phenomena, including the characteristics of life and the functions of the earth's elements in space and time. In a spatial context, geography subjects require the visualization of objects. To support students' spatial intelligence in distance learning, Augmented Reality (AR) can be used to enhance geography learning by helping students think logically, analytically, systematically, synthetically, critically, and creatively, and solve real problems. AR technology is a medium that adds digital information to the physical world, similar to virtual reality, which allows for human-computer interaction. Learning media that stimulate thoughts, feelings, attention, interests, and motivation can improve the learning process (Chandra et al., 2019).

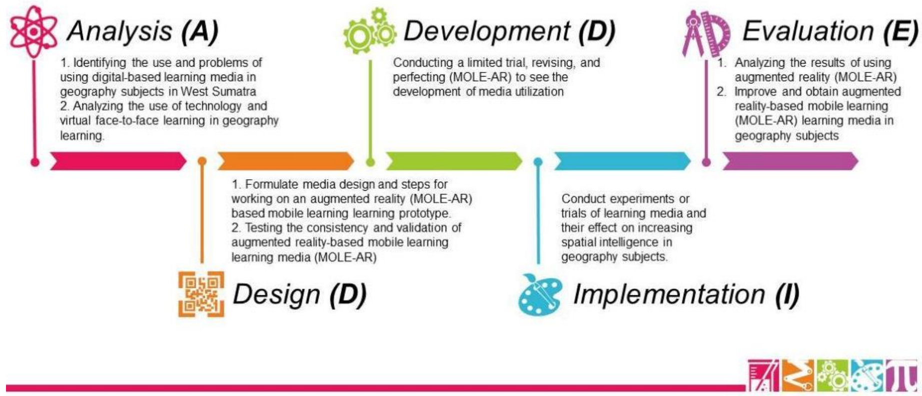
There has been limited research on mobile learning, especially in the field of geography education and in developing countries. This study is unique in that it developed a mobile application based on augmented reality to support geography education. Augmented reality was designed to enhance spatial intelligence, which is a crucial skill for successful geography education in the 21st century. Additionally, the use of augmented reality was intended to increase student engagement and interaction (Astuti, Suranto, & Masykuri, 2019). This research aims to contribute to the limited body of knowledge on the use of mobile learning in geography education, particularly in developing countries.

Various methods and technologies that are developing rapidly are used in the delivery of teaching and one of them is by using augmented reality technology. AR has the potential to motivate and enhance spatial intelligence by viewing and manipulating learning materials from different angles. Augmented Reality can assist in the development of students' higher-order thinking as well as in increasing understanding and changing the paradigm of students' learning perspectives in learning something. This is what motivated the researchers to submit a research proposal entitled MOLE-AR: Augmented Reality-Based Mobile Learning Innovation in Increasing Spatial Intelligence for High School Geography Subjects in West Sumatra.

METHODOLOGY OF RESEARCH

This type of research is research and development with the ADDIE development model, which is an interactive development design with basic stages that are effective, dynamic, and efficient. The steps for developing mobile learning media based on Augmented Reality (MOLE-AR) with the ADDIE model are described as follows:

FIGURE 1
THE STEPS FOR DEVELOPING MOLE-AR LEARNING MEDIA WITH THE ADDIE MODEL



This research used the ADDIE development model, which was developed by Reiser, (2001) and Mollenda and refined by Branch and Kopcha (2014). The ADDIE model is a five-step development model that covers the phases of analysis, design, development, implementation, and evaluation (Molenda, 2003). The steps of the ADDIE model are as follows:

1. **Analysis**. To understand the need for digital-based learning mediums in geography education, a survey was conducted among 60 senior high school geography teachers in West Sumatra. The survey aimed to identify the benefits and challenges of the current learning mediums, the benefits of technology in learning, and the virtual learning circumstances for geography. Additionally, the survey aimed to classify the necessity for using digital-based learning mediums to achieve the learning goals in geography education. By gathering this information, the researchers were able to identify the potential benefits and areas for improvement in the use of digital-based learning mediums in geography education.
2. **Design.** To create a successful mobile learning experience using augmented reality (MOLE-AR), it is important to follow a set of steps to ensure that the mediums are well-designed and effective. This includes formulating plans and designs for the MOLE-AR mediums, developing a prototype, arranging the mediums according to the planned design, testing the consistency of the mediums, and validating them to ensure their effectiveness. By following these steps, it is possible to create a high-quality MOLE-AR learning experience that engages and educates students.
3. **Development.** At this stage, researchers undertook a limited trial to see the development of the benefits of mobile learning based on augmented reality (MOLE-AR). Afterward, the researchers revised and refined mobile learning mediums based on augmented reality (MOLE-AR).
4. **Implementation.** To examine the effect of different learning media on spatial intelligence in geography, experiments were conducted using a quasi-experiment method with a paired sample t-test. The experiments were conducted at two schools, SMA Pembangunan UNP and SMA N 1 Pariaman, to analyze the results and determine the most effective learning media for improving spatial intelligence in geography subjects. This information can be used to inform the development and implementation of more effective learning materials in the future.
5. **Evaluation.** To create effective mobile learning materials in geography, it is important to analyze the results of using media based on augmented reality (MOLE-AR) and make improvements as necessary. This process involves evaluating the effectiveness of the MOLE-AR materials and making changes to ensure that they are engaging and effective for

learners. By following this process, it is possible to obtain high-quality MOLE-AR learning materials that can be used to enhance the learning experience in geography subjects.

RESULT

Analysis

TABLE 1
THE RESULTS OF THE ANALYSIS OF LEARNING CIRCUMSTANCES BASED ON GEOGRAPHY TEACHERS' USAGE OF ICT IN WEST SUMATRA

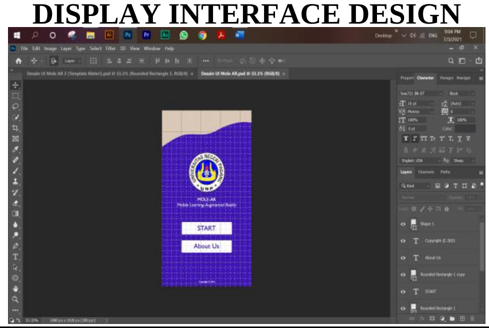
No	Indicator	Score
1	Virtual Learning Situation	75.33 %
2	Teacher Competency in Developing Learning Mediums Based on ICT	77.20 %
3	Problems of Geography Learning Mediums	73.48 %
4	The urgency of ICT-based geography learning media in West Sumatra	74.19 %

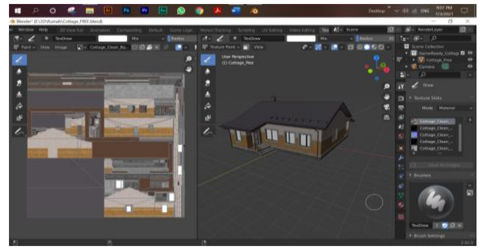
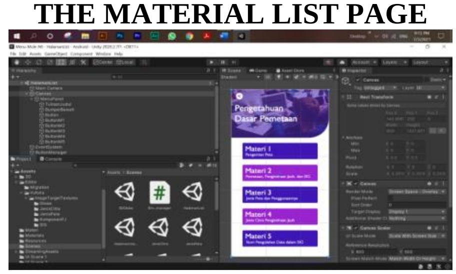
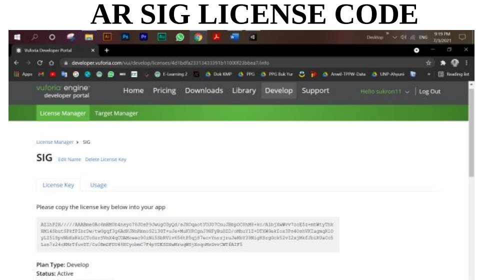
A needs analysis conducted among high school geography students and teachers in West Sumatra identified the need for mediums to facilitate distance learning and address the lack of available learning resources. Student-centered learning approaches, such as mobile learning, can be used as a solution to these problems and provide a way for students to access technology-based geography learning. Mobile learning can be an effective innovation in geography education, providing students with the resources they need to succeed in their studies.

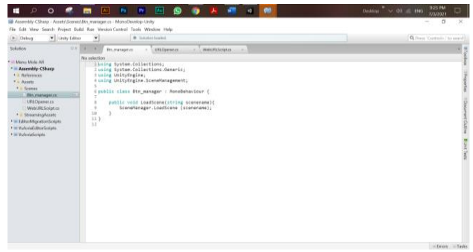
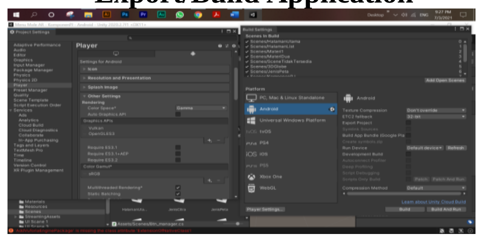
Design and Development

The stages in working on the Augmented Reality (MOLE-AR)-based Mobile Learning media application are as follows:

TABLE 2
STAGES OF WORKING ON MOLE-AR

No	Stages	Image
1	Plan the appearance and function of the application.	
2	To design the user interface of an application, Adobe Photoshop software can be used to create the display background, buttons, icons, and supporting images. These elements can be exported as .png files for use in the application. This process involves creating a visually appealing and user-friendly interface that will be easy for users to navigate and interact with. By carefully designing the interface, the application can be more effective and enjoyable for users.	**FIGURE 2** **DISPLAY INTERFACE DESIGN** 

3	Prepare 3D objects (3 Dimensions) that you wish to use, 3D objects are created using the blender software and take advantage of 3D objects available on the internet.	**FIGURE 3** **CREATING 3-DIMENSIONAL OBJECTS** 
4	After all the 3D objects, images, and icons are prepared, the next step is to start building the MOLE-AR application using the Unity software. Utilizing the MOLE-AR application on Unity uses the scene-per-scene technique, so that each display/page in the application will be in its scene.	
5	Arrange the user interface for each display/application page in Unity according to a predetermined design, the arrangement is carried out in each scene. In the MOLE-AR application, there are 13 views/pages.	**FIGURE 4** **PREPARATION OF THE UI/UX OF THE MATERIAL LIST PAGE** 
6	To create an Augmented Reality (AR) page, we have to get the license code and marker database from the Vuforia platform.	**FIGURE 5** **AR SIG LICENSE CODE** 
7	After the database and license code are obtained, the next step is to arrange 3D objects in Unity according to the database obtained in each AR scene.	**FIGURE 6** **ARRANGEMENT OF 3D OBJECTS** 

<table>
<tr><td>8</td><td>After all the views/pages are prepared in their respective scenes, the next step is to create a script for the button function commands in the application, the programming language used in the script is C#.</td><td>FIGURE 7
SCENE SWITCH BUTTON SCRIPT
</td></tr>
<tr><td>9</td><td colspan="2">After the script is prepared, then the script is entered into the inspector of each button so that the button can function according to the commands programmed in the script.</td></tr>
<tr><td>10</td><td>After all the work is done, the next step is to export the application to .apk format so that it can be installed using Android.</td><td>FIGURE 8
Export/Build Application
</td></tr>
<tr><td></td><td colspan="2">FIGURE 9
MOLE-AR RESULTS DISPLAY

</td></tr>
</table>

The results of expert validation of Augmented Reality (MOLE-AR)-based Mobile Learning mediums are as follows:

- Category
  - Very High : ≥86 %
  - High : 70-85 %
  - Medium : 53-69 %
  - Low : 37-52 %
  - Very Low : ≤36 %

TABLE 3
MEDIA EXPERT VALIDATION TEST

No	Aspect	Score
1	Display	86,7%
2	Typography	73,3%
3	Programming	93,3%
4	Completeness	86,7%

Validation tests conducted by experts on the MOLE-AR-based mobile learning mediums showed that the display aspect, including the video images and design and colors of the application page, received a "Very High" rating. The programming and completeness aspects were also evaluated as "Very High." However, the typographical aspect, including the ease of reading the material, the suitability of the type, variation, distance, line, and paragraph, received a "Medium" rating. These results suggest that while the visual elements of the MOLE-AR learning mediums are highly effective, there may be room for improvement in the typographical aspect to increase the overall effectiveness of the materials.

Then the results of expert validation of Augmented Reality (MOLE-AR)-based Mobile Learning learning materials are as follows:

TABLE 4
MATERIAL EXPERT VALIDATION TEST

No	Aspect	Score
1	Content Eligibility	86,7%
2	Language	73,3%
3	Presentation	86,7%
4	Graphic	73,3%

Validation tests conducted by experts on the MOLE-AR-based learning mediums evaluated the content and presentation of the materials in terms of their feasibility for achieving learning objectives, the accuracy of concepts, the completeness of material coverage, the ease of use of the media, and the clarity of examples. These aspects were rated as "Very High" by the experts. The linguistic and graphic aspects, including the accuracy of language and terminology, the layout of the material, the type and size of letters, and the use of color, were rated as "High." These results suggest that the MOLE-AR learning mediums are highly effective in terms of their content and presentation, with some room for improvement in the linguistic and graphic aspects.

Implementation

The syntax used in this study is as follows:

TABLE 5
USE OF MOLE-AR ACTIVITY

No.	Activity	Activity Teacher and Student
1	Introduction	The teacher opens the lesson by greeting, taking attendance, and apperception of learning
2	Contents	The teacher introduces the MOLE-AR application and the teacher's material helps the MOLE-AR installation process on students' androids The teacher divides the students into several groups Each group discusses the material using MOLE-AR Each group presents the results of the KD discussion after using MOLE-AR
3.	Closing	Teacher sets up a quiz via MOLE-AR The teacher carries out learning reflections after using MOLE-AR The teacher closes the lesson with conclusions, greetings, and reminders of the task for the next lesson.

The data for the achievement of Spatial Intelligence is based on the results of the pretest and posttest of students at SMA Pembangunan UNP and SMAN 1 Pariaman as follows:

TABLE 6
DATA ON SPATIAL INTELLIGENCE ACHIEVEMENTS

No	Spatial Intelligence Indicator	SMA Pembangunan UNP			SMAN 1 Pariaman		
		Pretest	Posttest	N-Gain	Pretest	Posttest	N-Gain
1	Defining a location	45.59	85.29	0.73	52.94	79.41	0.56
2	Describing a location	55.88	88.24	0.73	32.35	81.62	0.73
3	Explaining spatial connections	70.59	90.44	0.68	75.00	90.44	0.62
4	Making spatial comparisons	62.75	85.29	0.61	66.67	91.18	0.74
5	Spatial influence, limiting region	50.00	89.22	0.78	78.43	94.12	0.73
6	Putting a place into a spatial level	44.85	88.24	0.79	48.53	80.15	0.61
7	Creating a spatial transition graph	69.61	84.31	0.48	64.71	82.35	0.50
8	Identifying spatial equations	46.08	77.45	0.58	55.88	83.33	0.62
9	Seeing spatial patterns	45.10	72.55	0.50	36.27	77.45	0.65
10	Interpreting spatial combinations	56.62	77.21	0.47	76.47	92.65	0.69
11	Creating and using spatial models	50.00	85.29	0.71	58.09	85.29	0.65
12	Drawing spatial exceptions	51.96	75.49	0.49	50.98	88.24	0.76

The results of the pretest for spatial intelligence indicators at SMA Pembangunan showed that several indicators, including defining a location, examining spatial influence, delimiting a region, entering a place into a spatial level, identifying spatial equations, seeing spatial patterns, creating and using spatial models, and drawing spatial exceptions, were in the "low" category (scale of 37-52). Indicators including describing a location, making spatial comparisons, and interpreting spatial combinations were in the "medium" category (scale of 53-69). The indicator for explaining spatial connections and graphing spatial transitions was in the "high" category (scale of 70-85). The results of the posttest for spatial intelligence indicators at SMA Pembangunan UNP showed that several indicators, including defining a location, making spatial comparisons, graphing spatial transitions, identifying spatial equations, seeing spatial patterns, interpreting spatial combinations, creating and using spatial models, and drawing spatial exceptions, were in the "high" category (scale of 70-85). Indicators including describing a location, explaining spatial connections, examining spatial influence, delimiting a region, and entering a place into a spatial level were in the "very high" category (scale of ≥86). These results suggest that the use of MOLE-AR improved spatial intelligence in students at SMA Pembangunan UNP, with some indicators showing particularly significant improvement.

The results of the n-gain indicator of spatial intelligence in SMA Pembangunan UNP show that there was an increase in test scores or scores after using MOLE-AR. The indicators for explaining spatial connections, making spatial comparisons, making spatial transition graphs, identifying spatial equations, seeing spatial patterns, and interpreting spatial combinations fell into the "medium" category with an n-gain value of "0.3 g 0.7". On the other hand, the indicators for defining a location, describing a location, spatial influence, limiting the region, entering a place into the spatial level of making, and using a spatial model were classified as "high" with an n-gain value of "g > 0.7". The overall n-gain average was 0.62, which is in the "medium" category. This suggests that MOLE-AR was effective in improving the spatial intelligence of students at SMA Pembangunan UNP.

The results of the pretest and posttest of the spatial intelligence indicator at SMAN 1 Pariaman showed that the scores of the students improved. In the pretest, several indicators, such as entering a place into the spatial level and seeing spatial patterns, were in the "very low" category (≤36), while others, like describing a location and drawing spatial exceptions, were in the "low" category (37-52). Several other indicators, like defining a location and creating and using a spatial model, were in the "moderate" category (53-69). The remaining indicators, including explaining spatial connections and interpreting spatial combinations, were in the "high" category (70-85). These results suggest that there was an improvement in the spatial intelligence of the students at SMAN 1 Pariaman.

In the Posttest, the indicators for defining a location, describing a location, entering a place into a spatial level, making a spatial transition graph, identifying spatial equations, and seeing spatial patterns were in the "high" category on a "70-85" scale. The indicators for explaining spatial connections, making spatial comparisons, spatial influences, limiting regions, and interpreting spatial combinations were in the "very high" category with a scale of "≥86". This suggests that the students at SMAN 1 Pariaman had a significant improvement in their spatial intelligence after the intervention.

Evaluation

Paired-Sample t-test Before and After Learning Process on Spatial Intelligence based on the pretest and post-test results of students at SMA Pembangunan UNP and SMAN 1 Pariaman as follows:

TABLE 6
PAIRED-SAMPLE T-TEST BEFORE AND AFTER THE LEARNING PROCESS

No	Data	Mean	SD	T	df	Sig. (2-tailed)
1	SMA Pembangunan UNP	-29,63	7,31	-26,63	33	0,000
2	SMA N 1 Pariaman	-26,84	10,79	-14,51	33	0,000

The results of the Paired-Sample t-test showed that the t count was -23.63 and the level of significance (sig. 2-tailed) was 0.000, with a degrees of freedom of 33. Since the level of significance in this study was set at 0.05 and the value of sig. (2-tailed) was less than 0.05 (0.000 < 0.05), it can be concluded that there was a statistically significant difference in spatial intelligence between the pretest and posttest in SMA Pembangunan UNP. This suggests that Mole AR was effective in improving the spatial intelligence of students in geography subjects.

The results of statistical testing of spatial intelligence at SMA N 1 Pariaman using SPSS version 26.0 showed that there were significant differences in the spatial intelligence of students before and after learning using Mole-AR. The Paired-Sample t-test table revealed that the t-count value was -14.51, with a degree of freedom (df) of 33 and a sig. (2-tailed) of 0.000. When the level of significance was set at 0.05, it was found that the value of sig. (2-tailed) was smaller than 0.05 (0.000 < 0.05). This indicates that there was a statistically significant difference in spatial intelligence between the pretest and posttest at SMA N 1 Pariaman. This suggests that Mole-AR was effective in improving the spatial intelligence of students in geography subjects at this school.

The N-Gain Mole-AR data on Spatial Intelligence based on the pretest and posttest results of students at SMA Pembangunan UNP and SMAN 1 Pariaman are as follows:

TABLE 7
MOLE-AR N-GAIN DATA ON SPATIAL INTELLIGENCE

No	Schools	Pretest	Posttest	N-Gain
1	SMA Pembangunan UNP	53,68	83,31	0,64
2	SMA N 1 Pariaman	58.90	85,74	0,65

The use of Mobile Learning (MOLE-AR) based on augmented reality appears to have the potential to improve spatial abilities, as shown by the data in Table 6. The results from a study at SMAN 1 Pariaman showed that certain indicators, such as defining a location and interpreting spatial combinations, improved by a medium amount (n-gain value of “0.3 g 0.7”) after using MOLE-AR. Other indicators, like describing a location and drawing spatial exceptions, improved by a high amount (n-gain value of “g > 0.7”). The overall average n-gain was 0.65, indicating a medium improvement in test scores after using MOLE-AR. These findings suggest that MOLE-AR may be effective in improving spatial ability.

The results of the Focus Group Discussion between the researcher and the teachers revealed that the teachers found the augmented reality-based mobile learning product to be highly beneficial, particularly in geography education. Geography has a wide range of topics, and mobile learning can be a useful support for teaching in the classroom. The students also appreciated the addition of augmented reality-based mobile learning to their learning experience and expressed hope that it could be used to cover all the materials in their school curriculum. Overall, it seems that this mobile learning approach has the potential to enhance the learning experience for both teachers and students.

DISCUSSION

The study of geography is closely related to physical and social conditions on Earth. According to Craig (2013), the use of Augmented Reality (AR) can enhance the learning of geography by bringing virtual elements into real-world environments, allowing students to interact with simulations of geographical phenomena. This can support the development of spatial intelligence and improve students’ critical thinking, analytical, and creative skills. Additionally, research has demonstrated the effectiveness of AR-based learning media in displaying physical phenomena (Yusuf, Ismail, Hamzah, Amin, & M Arsad, 2023). Overall, the incorporation of AR in geography education can help students think logically, systematically, and synthetically, and solve real-world problems.

In this era of globalization, the use of information technology has become essential. With the increasing importance of science and technology, educators must possess the necessary technological knowledge and skills to support improvements in the learning process. To enhance the effectiveness of learning, educators must be competent in using information technology in education to achieve educational goals (Atlantis &

Cheema, 2015; Baran, Chuang, & Thompson, 2011). In order to meet these demands, it is important for educators to continuously strive to improve their technological knowledge and skills.

Based on the results of this study, there was an increase in the spatial abilities of geography students after using augmented reality-based learning mediums. The results of this study are following previous research which states that augmented reality technology increases learning effectiveness and learning interest among students with real-world scenarios (Abd Halim et al., 2022; Dennen & Hao, 2014). Mobile devices are now regarded as just a means of communication and interaction between students and teachers. They serve as indispensable teaching tools, contributing to the overall development of the educational process and introducing innovative teaching methods (Daineko, Tsoy, Seitnur, & Ipalakova, 2022). The use of mobile Augmented Reality (AR) technology in geography education, particularly for teaching geomorphology topics, has been shown to improve students' achievement and reduce their cognitive load, and students generally have positive views of this technology (Turan, Meral, & Sahin, 2018).

According to the results of a study conducted at two schools (SMA Pembangunan UNP and SMA N 1 Pariaman), the use of augmented reality-based mobile learning led to an improvement in students' spatial intelligence, as indicated by an increase in n-gain in the moderate category. Both teachers and students reported that this approach was effective in geography education, with teachers noting its numerous benefits and students finding it easy to use and engaging. The MODE-AR application was found to be particularly useful for both face-to-face and virtual learning, as it helped students understand complex material and made learning more interactive and enjoyable. Overall, it appears that augmented reality-based mobile learning is a valuable tool for enhancing geography education.

CONCLUSIONS

The results of the pretest and posttest conducted on students at the SMA Pembangunan UNP and SMAN 1 Pariaman showed an increase in the spatial abilities of students in the basics of Mapping, Remote Sensing, and Geographic Information Systems, class X's odd semester in senior high schools in West Sumatra. It can be concluded that Augmented Reality (AR)-based mobile learning mediums are able to provide the potential to be able to facilitate students in learning materials related to spatial intelligence.

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REFERENCES

Abbas, M., Hwang, G.-J., Ajayi, S., Mustafa, G., & Bilal, M. (2021). Modelling and exploiting taxonomic knowledge for developing mobile learning systems to enhance children's structural and functional categorization. *Computers and Education: Artificial Intelligence*, *2*, 100007. https://doi.org/10.1016/j.caeai.2021.100007

Abd Halim, N.D., Hong, O.A., Zulkifli, N.N., Jumaat, N.F., Mohd Zaid, N., & Mokhtar, M. (2022). Designing Game-Based Learning Kit with Integration of Augmented Reality for Learning Geography. *International Journal of Interactive Mobile Technologies (IJIM)*, *16*(02), 4–16. https://doi.org/10.3991/ijim.v16i02.27377

Adedokun-Shittu, N.A., Ajani, A.H., Nuhu, K.M., & Shittu, A.K. (2020). Augmented reality instructional tool in enhancing geography learners academic performance and retention in Osun state Nigeria. *Education and Information Technologies*, *25*(4), 3021–3033.

Al-Adwan, A.S., Al-Madadha, A., & Zvirzdinaite, Z. (2018). Modeling Students' Readiness to Adopt Mobile Learning in Higher Education: An Empirical Study. *The International Review of Research in Open and Distributed Learning*, *19*(1). https://doi.org/10.19173/irrodl.v19i1.3256

Ally, M., & Prieto-Blázquez, J. (2014). Quin és el futur de l'aprenentatge mòbil en l'educació? *RUSC. Revista de Universidad y Sociedad Del Conocimiento*, *11*(1), 142. https://doi.org/10.7238/rusc.v11i1.2033
Al-Mashhadani, M.A., & Al-Rawe, M.F. (2018). The future role of mobile learning and smartphones applications in the Iraqi private universities. *Smart Learning Environments*, *5*(1), 28. https://doi.org/10.1186/s40561-018-0077-7
Astuti, F.N., Suranto, S., & Masykuri, M. (2019). Augmented reality for teaching science: Students' problem solving skill, motivation, and learning outcomes. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *5*(2), 305–312.
Atlantis, E., & Cheema, B.S. (2015). Effect of audience response system technology on learning outcomes in health students and professionals: An updated systematic review. *International Journal of Evidence-Based Healthcare*, *13*(1), 3–8.
Baran, E., Chuang, H.H., & Thompson, A. (2011). TPACK: An emerging research and development tool for teacher educators. *Turkish Online Journal of Educational Technology*, *10*(3), 722–727. Retrieved from https://eric.ed.gov/?id=EJ946646
Chandler, D., & Hwang, H. (2015). Learning From Learning Theory: A Model of Organizational Adoption Strategies at the Microfoundations of Institutional Theory. *Journal of Management*, *41*(5), 1446–1476. https://doi.org/10.1177/0149206315572698
Chandra, D., Wilis, R., Susetyo, B.B., Rahmi, L., Arief, D.A., Prarikeslan, W., … Ramadhan, R. (2019). *The Making of Solar Systems as One of Geography Learning Media in Sma N 2 Batang Anai, Padang Pariaman Regency and Sma N 5 Bukittinggi, Bukittinggi City*, *3*(2), 118–122.
Daineko, Y., Tsoy, D., Seitnur, A., & Ipalakova, M. (2022). Development of a Mobile e-Learning Platform on Physics Using Augmented Reality Technology. *International Journal of Interactive Mobile Technologies (IJIM)*, *16*(5), 4–18. https://doi.org/10.3991/ijim.v16i05.26961
Dennen, V.P., & Hao, S. (2014). Intentionally mobile pedagogy: The M-COPE framework for mobile learning in higher education. *Technology, Pedagogy and Education*, *23*(3), 397–419. https://doi.org/10.1080/1475939X.2014.943278
Dhawan, S. (2020). Online Learning: A Panacea in the Time of COVID-19 Crisis. *Journal of Educational Technology Systems*, *49*(1), 5–22. https://doi.org/10.1177/0047239520934018
Hakiki, R., Muchson, M., Sulistina, O., & Febriana, A. (2022). The Development of Learning Media Based on Augmented Reality, Hologram, and Ludo Game on The Topic of Molecular Shapes. *International Journal of Interactive Mobile Technologies (IJIM)*, *16*(4), 70–84. https://doi.org/10.3991/ijim.v16i04.28989
Hofer, M., Grandgenett, N., Harris, J., & Swan, K.O. (2011). *Testing a TPACK-based technology integration observation instrument*. Society for Information Technology & Teacher Education International Conference. Retrieved from https://www.learntechlib.org/p/37015/
Krull, G., & Duart, J.M. (2017). Research Trends in Mobile Learning in Higher Education: A Systematic Review of Articles (2011 – 2015). *The International Review of Research in Open and Distributed Learning*, *18*(7). https://doi.org/10.19173/irrodl.v18i7.2893
Molenda, M. (2003). In search of the elusive ADDIE model. *Performance Improvement*, *42*(5), 34–37.
Nofrion, N., Wijayanto, B., Wilis, R., & Novio, R. (2018). Analisis Technological Pedagogical and Content Knowledge (TPACK) Guru Geografi di Kabupaten Solok, Sumatera Barat. *JURNAL GEOGRAFI*, *10*(2), 105. https://doi.org/10.24114/jg.v10i2.9070
Rayuwati, R. (2020). How educational technology innovates distance learning during pandemic crisis in remote areas in Indonesia? *International Research Journal of Management, IT and Social Sciences*, *7*(6), 161–166. https://doi.org/10.21744/irjmis.v7n6.1032
Rius, À., Clarisó, R., & Masip, D. (2014). Projectes dels estudiants per a potenciar l'aprenentatge mòbil en l'ensenyament superior. *RUSC. Revista de Universidad y Sociedad Del Conocimiento, 11*(1), 192. https://doi.org/10.7238/rusc.v11i1.1901

Sayibu, M., Jianxun, C., Akintunde, T.Y., Olayemi Hafeez, R., Koroma, J., Amosun, T.S., & Shahani, R. (2021). Nexus between students' attitude towards self-learning, Tencent APP usability, mobile-learning, and innovative performance. *Social Sciences & Humanities Open*, *4*(1), 100217. https://doi.org/10.1016/j.ssaho.2021.100217

Sophonhiranrak, S. (2021). Features, barriers, and influencing factors of mobile learning in higher education: A systematic review. *Heliyon*, *7*(4), e06696. https://doi.org/10.1016/j.heliyon.2021.e06696

Sprenger, D.A., & Schwaninger, A. (2021). Technology acceptance of four digital learning technologies (classroom response system, classroom chat, e-lectures, and mobile virtual reality) after three months' usage. *International Journal of Educational Technology in Higher Education*, *18*(1), 8. https://doi.org/10.1186/s41239-021-00243-4

Traxler, J. (2007). Defining, Discussing and Evaluating Mobile Learning: The moving finger writes and having writ . . . . *The International Review of Research in Open and Distributed Learning*, *8*(2). https://doi.org/10.19173/irrodl.v8i2.346

Turan, Z., Meral, E., & Sahin, I.F. (2018). The impact of mobile augmented reality in geography education: Achievements, cognitive loads and views of university students. *Journal of Geography in Higher Education*, *42*(3), 427–441.

Vallejo-Correa, P., Monsalve-Pulido, J., & Tabares-Betancur, M. (2021). A systematic mapping review of context-aware analysis and its approach to mobile learning and ubiquitous learning processes. *Computer Science Review*, *39*, 100335. https://doi.org/10.1016/j.cosrev.2020.100335

Wong, E.Y.W., Kwong, T., & Pegrum, M. (2018). Learning on mobile augmented reality trails of integrity and ethics. *Research and Practice in Technology Enhanced Learning*, *13*(1), 22. https://doi.org/10.1186/s41039-018-0088-6

Wong, H.C. (2014). A study of mobile learning for higher education students in Guangzhou. *SpringerPlus*, *3*(S1), P3,-2193-1801-3-S1-P3. https://doi.org/10.1186/2193-1801-3-S1-P3

Yuan, Y.-P., Wei-Han Tan, G., Ooi, K.-B., & Lim, W.-L. (2021). Can COVID-19 pandemic influence experience response in mobile learning? *Telematics and Informatics*, *64*, 101676. https://doi.org/10.1016/j.tele.2021.101676

Yusuf, Y.A.M., Ismail, I., Hamzah, W.M.A.F.W., Amin, M.A.M., & M Arsad, M.A. (2023). A Literature Review on Mobile Augmented Reality in Education. *International Conference on Business and Technology*, pp. 875–888. Springer.

Zhang, Q., & Wang, Y. (2020). A 3D mobile positioning method based on deep learning for hospital applications. *EURASIP Journal on Wireless Communications and Networking*, (1), 170. https://doi.org/10.1186/s13638-020-01784-4