Integration of Mobile Augmented Reality Applications for Engineering Mechanics Learning with Interacting 3D Objects in Engineering Education

Waskito*, Aprilla Fortuna, Febri Prasetya, Rizky Ema Wulansari, Rahmat Azis Nabawi, and Afdal Luthfi

Faculty of Engineering, Universitas Negeri Padang, Indonesia
Email: waskito@ft.unp.ac.id (W.); aprillafortuna@student.unp.ac.id (A.F.); febriprasetya@ft.unp.ac.id (F.P.); rizkyema@ft.unp.ac.id (R.E.W.); raazna@ft.unp.ac.id (R.A.N.); afdalluthfi02@gmail.com (A.L.)
*Corresponding author
Manuscript received August 15, 2023; revised October 7, 2023; accepted October 27, 2023; published March 4, 2024

***Abstract*—The development of Augmented Reality (AR) technology has proliferated in the educational arena. The results of subjective observations of engineering mechanics learning show the decline in student interest and understanding caused by conventional teaching methods, which are the biggest obstacles in the learning process, thus impacting students' cognitive abilities. This study develops AR as an instructional media for engineering mechanics using the Analyse, State, Select, Utilise, Require, and Evaluate (ASSURE) instructional design model with an R&D approach. This study used performance assessment instruments, questionnaires, and interviews with students and lecturers as the primary data. The subjects of this study were 103 students of Mechanical Engineering Vocational Education at Universitas Negeri Padang in the 2020–2021 academic year. The results showed that the use of AR-based learning media had a positive impact on students' understanding of basic concepts and skills. In addition, AR media support independent learning and provide direct feedback to students. The acquisition of validation results from material experts is 88.48% (very valid), media experts of 89.26% (very valid), and linguists of 87.41% (very valid). The average practicality test results from the lecturer's responses were 89.70% (very practical) and 81.63% (practical) student responses. In conclusion, the results of developing mobile AR applications that are declared valid and practical can provide a more interactive and exciting learning experience for students to increase their interest and understanding of learning. Therefore, mobile AR is an exciting option for further integrating engineering education into higher education.**

***Keywords*—3D object, augmented reality, engineering mechanics, future technology, mobile application**

I. Introduction

Everyone must cultivate a critical, creative thinking and innovative mindset in today's digital world. These skills are essential for producing quality human resources and contributing to education in Indonesia. Indonesia ranks 87 of 157 countries on the World Bank 2018 Human Capital Index [1–3]. Quality education is essential in preparing Indonesians to live in the era of Society 5.0 and Industrial Revolution 4.0 [4, 5]. Moreover, the best technology-based education system is snowballing in countries such as Japan, China, Singapore, and Korea [6, 7]. It was an opportunity for the Indonesian people to follow developed countries on the Asian continent in developing education systems and encouraging character education integrated with science and technology [8].

Education's value rests in the fact that it allows for the betterment of human resources in teaching, research, and community service, all of which actively contribute to the transfer of potential from one generation to the following [9–12]. The rapid development of technology affects aspects of education, especially in the presence of the Minister of Education and Culture, who has instituted a policy called Merdeka Learning Independent Campus (*Indonesia: Merdeka Belajar Kampus Merdeka/MBKM*). The policy aims to provide students with skills ready to be implemented in the workplace, especially aspects of information technology that focus on the quality of human resources ready to compete. It is a form of implementation of higher education in building 21st-century skills in students with web-based learning models, blended, e-learning, mobile, and distance learning [13–15]. Implementing the Independent Campus the curriculum requires all universities to implement information technology-based learning media innovations using digital media, such as learning videos, interactive multimedia, augmented reality, virtual reality, mixed reality, and hologram media [16–18]. The emergence of the programme provides access to educators and students to improve the quality of learning outcomes [19], and self-development so that the learning applied adapts to the needs of students and creates a more independent, creative, and innovative learning atmosphere.

Based on observation findings at the Department of Mechanical Engineering at Universitas Negeri Padang. One of the problems obtained is the decline in student interest and motivation due to traditional teaching methods, such as blackboard media, one-way lecture models, individual assignments, and written exams, which are still often used, affecting the motivation to learn engineering mechanics courses that seem monotonous [20, 21]. Although these traditional teaching methods are still widely used, education must continue developing and introducing more innovative, interactive, and engaging methods to maintain students' interest and motivation and improve their learning outcomes [22, 23]. Additionally, the post-COVID-19 pandemic effect has altered the face-to-face learning pattern, with a disproportionately high number of distance learning implementations employed as a substitute for the teaching process [24, 25]. Therefore, there is a need for educational innovation in the classroom that fosters a new learning environment through interactive learning media to develop instruction that actively involves students in the learning process [26].

The aspects that influence a teacher's readiness are theoretically presented in the study "a critical outlook at augmented reality and its adoption in education", with the

doi: 10.18178/ijiet.2024.14.3.2057

findings that the teaching attitudes of educators have a clearer understanding of the context of social and technical capacity in the classroom [27]. However, the direct application of AR technology requires special training through socialisation or application instruction. As for empirical evidence on future research recommendations, integrating AR technology into education can have a positively impact [28, 29]. Therefore, AR technology becomes an opportunity for cooperation between researchers as application prototype developers and lecturers as teachers, realising and evaluating each component of AR in meeting learning needs to be more concrete [30, 31].

Augmented Reality (AR) is a cutting-edge technology that can show moving 3D models in real time, connecting the digital and physical worlds [32, 33]. In education, Augmented Reality technology is used as a means of teaching, which aims for educators to deliver material that helps students better understand the material provided. Advances in technology provide opportunities for students to learn using mobile AR applications in face-to-face or distance learning to build a synchronised learning model between lecturers and students in real-time lectures [34–37]. However, it found that integrating AR into learning still requires a large Internet storage capacity, and the resulting visuals cannot move in 360 ° animation [38]. The advantages of integrating AR development in this study are that the mobile device does not require the internet, the application size is relatively small at 70 MB, and the visualisation of learning in 360 ° moving animation [39, 40]. The combination of AR-based learning can increase the efficiency of learning engineering mechanics, which initially takes twenty-four hours of face-to-face learning and can now be learned in four hours more effectively up to twenty hours of interactive, collaborative, independent learning [41–43].

Mobile Augmented Reality-based learning media aims to create an interactive learning experience in 3D objects that appear in the real world with real-time moving animations. It is a learning innovation that increases student motivation and cognitive abilities. Therefore, this research aims to create a mobile application for Android that uses AR to improve the quality of learning in engineering mechanics for students in mechanical engineering vocational education. The following research questions were answered to achieve the objectives of this study:

1) How are the development results of mobile augmented reality for engineering mechanics learning?
2) How are augmented reality's validity and practicality results for engineering mechanics learning?

II. Methodology

The ASSURE instructional design model is a research and development model that includes six stages, namely: "analyse learners," "state objectives," "select method," "utilise, media, and material"," required learner participation", and "evaluation" [44, 45]. This research produces mobile learning products based on AR technology, including teaching materials (e-modules), learning videos, and animation simulations with back-sound and engineering mechanics material infographics. The study subjects were 103 Mechanical Engineering Vocational Education programme students at Universitas Negeri Padang for the 2020–2021 academic year.

The research and development stage consists of six stages: 1) Analyse learners: Aims to analyse student needs related to media and learning outcomes by considering the characteristics and initial learning competencies. 2) State objectives: The Independent Campus curriculum used in this study aims to prepare student resources with the skills needed in the world of work in technology and information. 3) Select method: Design the initial appearance of the application with the design results outlined in the use case diagram adapted to learning Engineering Mechanics. 4) Utilise media and materials: Serves to develop mobile AR applications that use black box testing and validity tests. 5) Required learner participation: Involving lecturers as teachers and students who take part in learning engineering mechanics by conducting practical tests that encourage the achievement of learning objectives. 6) Evaluation is the final stage in the ASSURE research model, which focuses on revision and student learning outcomes. However, this research focuses on the fifth stage, which involves lecturers and students using mobile AR applications in engineering mechanics courses. The ASSURE development model is demonstrated in Fig. 1 below [44].

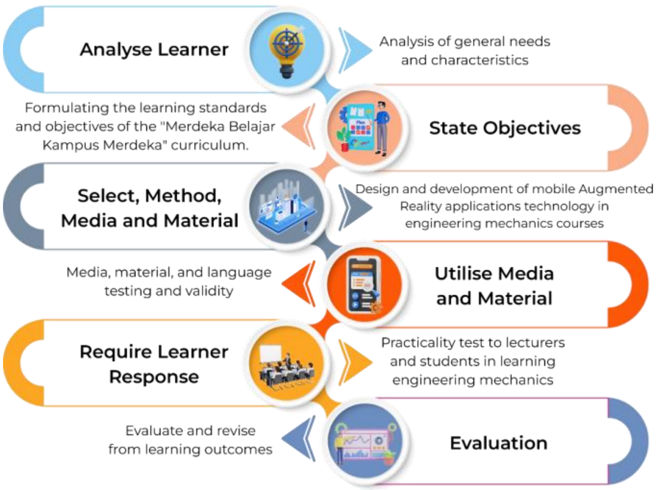

Fig. 1. ASSURE instructional design model.

The research instrument uses a validation questionnaire for experts, practitioners, and students to collect data about the developed media, as stated by Nieveen [46]. Instruments on mobile Augmented Reality applications-based instructional media questionnaire validated by nine experts, with three experts assessing aspects of media, material, and language who are Doctors and Professors with 30–40 years of teaching and research experience in the Universitas Negeri Padang [47]. The assessment of each question item pays attention to the language structure. The accuracy aspect of a valid measurement can perform its measuring function appropriately and has high accuracy [48]. The application has successfully passed the validation test with nine experts, revision, and evaluation of application prototypes, and the practicality test is used to determine the ease of use of the media based on the responses of three practitioners/lecturers who teach engineering mechanics courses and 103 Mechanical Engineering Education students in 2020–2021 by random sampling. Data collection using a questionnaire via Google form with Likert scale-based measurements with several positive and negative statements on application development results. This includes a) needs analysis based on the essential competencies of the engineering mechanics curriculum, b) the selection of media formats and application prototypes that have been developed, c) compiling validity and practicality questionnaires, d) testing the validity of material experts on aspects of learning design, material presentation, and quality of learning, e) testing the validity of media experts on aspects of user interface quality, software navigation, and interactivity, f) testing the validity of linguists on aspects of language in the matter, communicative language, and media guide language, g) three expert validators provide validation, material experts, media experts, and linguists with nine expert validators , h) once the media has been deemed valid, it is revised and evaluated based on the validators' comments, suggestions, and recommendations, and i) the practicality test aims to see the responses of lecturers and students to the use of mobile AR with a simple random sampling technique, the data obtained will be processed using Excel software [49].

The results of the research questionnaire validation consisted of material experts, media experts, and linguists, obtained using a Likert scale of 1 to 5. The assessment evaluates the results of developing Augmented Reality-based learning media for learning engineering mechanics. The validity and practicality tests used the following formula:

$$P = \frac{\sum x}{\sum xi} \times 100\%$$

Information:

P: Percentage of validity and practicality values (%)

$\sum x$: Total overall score of respondents obtained

$\sum xi$: Maximum number of marks in one aspect

The percentage value of validity and practicality is obtained based on the formula expressed by R. Hakiki [50]. Table 1 presents a classification based on the mobile augmented reality applications' validity and practicality criteria.

Table 1. Scale of validity and practicality criteria

Validity		Practicality	
Percentage (%)	Criteria	Percentage (%)	Criteria
81–100	Very valid	85–100	Very practical
61–80	Valid	75–84	Practical
41–60	Valid enough	65–74	Pretty Practical
21–40	Invalid	55–64	Less practical
0–20	Very invalid	0–54	Impractical

The next stage in developing mobile Augmented Reality applications is revision and evaluation based on the validators' criticisms, comments, and suggestions. The practicality test focuses on obtaining responses to ease of use from lecturers and students who have used the mobile augmented reality that researchers have successfully developed.

III. Results and Discussion

A. Analysing Learner

This study generated an AR-based mobile application for the engineering mechanics course of Mechanical Engineering Vocational Education students at Universitas Negeri Padang. The learning method frequently used is the lecture method, PowerPoint presentations, and other conventional teaching materials that make learning less varied and effective. This learning method is not appropriate, especially since the learning of engineering mechanics is relatively complex because the theory presented focuses on the motion of an object and the effect of force as expressed by participants during the interview process. An impact is a low motivation to learn. Students lack an understanding of engineering mechanics learning both in theory and practice, which causes learning outcomes to be less than optimal [51].

B. State Objectives

The learning objectives based on the Independent Campus curriculum for the engineering mechanics course of the Mechanical Engineering Vocational Education study program at Universitas Negeri Padang with learning achievement criteria are as follows: a) understand the basic concepts of the scope of engineering mechanics and their use in design, b) understand the basic concepts of moments and forces and their summation, c) understand the basic concepts of equilibrium in the structure of the machine frame and distributed loads; and, d) understand the basic concepts of plasticity and residual strain. After conducting the observation and literature review, the formulation of learning objectives is used as a reference to develop AR-based instructional media in engineering mechanics learning that have been set based on a thorough examination of students' requirements.

C. Select, Method, Media, and Material

The developed instructional media is called Engineering Mechanics-AR, and its features in this application include examples such as e-modules, educational video lessons, 3D object animations accompanied by a background sound, and a description panel of marked objects that provide details about engineering mechanics learning. The primary and supporting software used in designing Engineering Mechanics-AR applications is a) Blender, which is software for building 3D objects with animation simulations that loop time; b) Vuforia Engine SDK, which functions to build augmented reality developed by Qualcomm with computer vision as marker-based tracking that realises 3D objects; c) Android Studio, which is an IDE development environment for building mobile learning applications that have efficient functionality and provide an easy-to-use user interface on Android devices; d) Unity 3D, which integrates 3D objects as an Android platform in creating mobile augmented reality visualisations by combining all the design results from the blender software, Vuforia engine SDK, and android studio with engine systems that use the C# programming language, Javascript, and boot scripts built in APK format and on Android mobile application devices.

The initial design stage of the developed mobile augmented reality application is displayed on the Usecase Diagram with the target user using an Android device to run the application. There are several steps in the development of the Engineering Mechanics-AR application, namely a) design the blueprint display layout, b) build the user interface in Unity and 3D objects in the blender, c) combine all assets that have been designed in Unity 3D application based on the needs analysis, d) build the application in the form of a prototype that can be run on mobile learning, and e) run the prototype that can be run on mobile learning, and e) run the application and activate the rear camera of the smartphone directed at the marker by creating 3D objects according to the layout that has been successfully designed. Fig. 2 shows the steps for using the Engineering Mechanics-AR application, which a lecturer and student user can run via an Android device. Starting from installing the application and registering a user account, after connecting, the user will enter the main menu, which can be used as needed; in particular, users have to demonstrate 3D object animation on engineering mechanics learning materials that have features such as e-modules, learning videos, practice questions, and discussion forums between lecturers and students that can be carried out remotely.

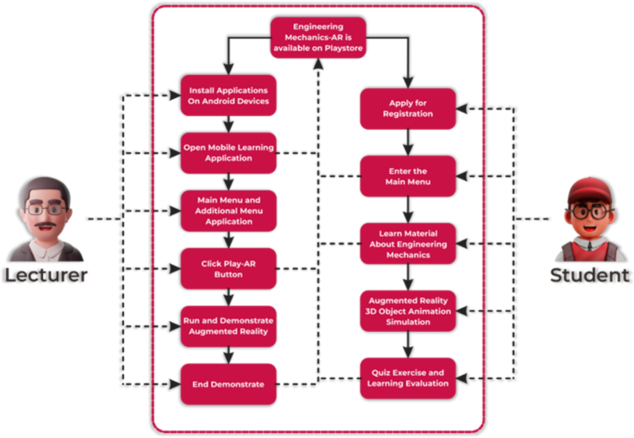

Fig. 2. Use case diagram of engineering mechanics-AR.

Fig. 2 presents a mobile augmented reality application design that is stand-alone, self-contained, self-instructional, and user-friendly. In detecting the marker at the coordinate point, the system must define the marker in realising the 3D object in real-time and adjust to the user's needs.

D. Utilising Media and Material

Answer for RQ1: The impact of the application of the results of the development of mobile augmented reality learning engineering mechanics.

Augmented reality technology helps people understand abstract concepts by visualising them, making it easier to imagine a model of an object. Learning applications that use AR, especially in self-paced learning, tend to attract students by offering a learning experience demonstrated by animated simulations of 3D objects that explain the visualised material in more detail. The following technology and learning media are seen as a means to encourage students to interact more actively and participate in the learning process.

Fig. 3 shows the user interface in the application, which is designed in such a way with navigation, namely: a) The main menu serves as the main page of the application after passing through the splash screen, b) the Video settings function in adjusting the resolution and aspect ratio of the learning video display in applications with sizes 720p (HD): 1280×720, 480p (SD): 854×480, c) Audio settings set the high and low volume of the music and back sound of the application with a scale of 0–100, d) Developer Profile Display about the app developer, and e) Instructions for use so that the user knows how to install and uninstall the application step by step.

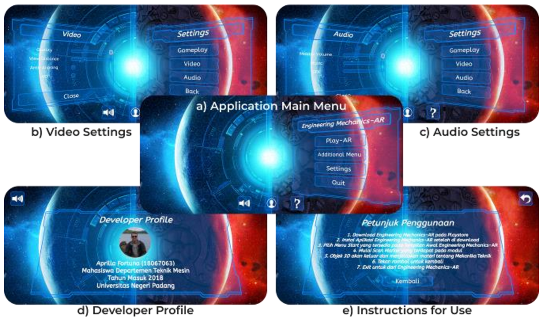

Fig. 3. The main menu of the Engineering Mechanics-AR application.

The presentation of information in Fig. 4 on the Additional Menu in the Engineering Mechanics-AR application assists students in developing their cognitive skills while studying the engineering mechanics course. It is intended to foster 21st-century skills in the next generation of students by encouraging critical thinking, creativity, and innovation. a) The main menu serves as the primary navigation centre that provides access to various features, functions, and parts of the application that have been developed; b) the video menu is presented to improve students' initial understanding of learning engineering mechanics presented in the form of animated videos with four materials, c) the e-module menu is designed in PDF form which includes material, namely: scalar and vector, the moment of force, magnitude and summation, Varignon's theorem, and fundamental principles, d) Marker menu functioned as a marker to realise 3D objects from Augmented Reality using the rear camera of the user's mobile application, and e) Quiz menu is used to evaluate the extent to which students understand the learning of engineering mechanics so that lecturers can provide consumption of learning materials based on student needs.

Fig. 4. Additional menu display.

Fig. 5 shows the results of the marker menu development as an activation to realise 3D objects marked in the Unity application scanned by the user's mobile application camera. Five markers were made in integrating 3D AR objects: a) marker of the moment of force, b) marker of the force of motion, c) vector marker, d) marker of the equilibrium of a rigid body, and e) marker of the truss structure.

Based on the Independent Campus curriculum, the illustration in Fig. 6 represents a 3D object, the main subject of this research, namely mobile AR in learning engineering mechanics. This link shows a successfully developed application: https://bit.ly/EngineeringMechanics-AR. The 3D objects displayed can move interactively, if the user points the Android device camera at the marker, the visualisation of the engineering mechanics learning animation appears. The potential and benefits of this media can enhance the learning experience by helping students understand abstract concepts more visually in the real world through 3D visualisation. The results of AR research in building 3D objects consist of five AR objects displayed in Fig. 6, namely: a) AR forces of motion, b) AR moments of force, c) AR vectors, d) AR equilibrium of rigid bodies, and e) AR skeletal structures, as well as animation simulations with back sound and caption panels.

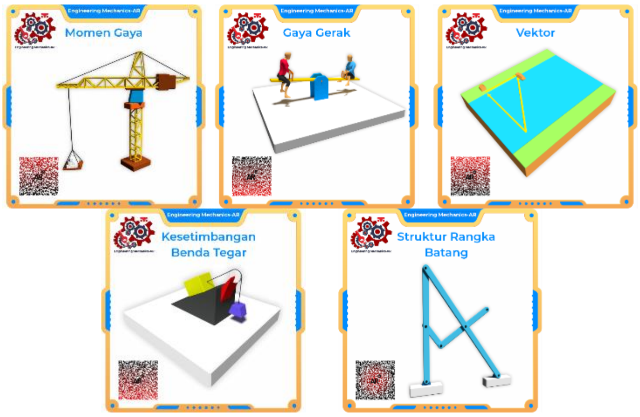

Fig. 5. Augmented reality marker to display 3D objects.

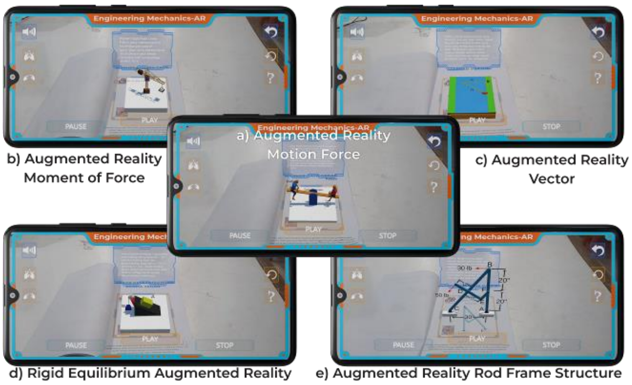

Fig. 6. 3D object visualisation mobile augmented reality.

Fig. 7 shows a quiz menu to measure how well students understand engineering mechanics learning after using all the features in the application, such as learning videos, e-modules, and 3D Object Augmented Reality. The presentation of Fig. 7 displays features consisting of a) a quiz menu with 5–10 objective questions and an automatic scoring system, b) a quiz display if the correct answer will appear as a correct notification, c) a quiz display if the wrong answer will appear as a wrong notification, d) a user display that has completed the entire quiz given, and finally, and e) an assessment system with a bayesian network approach that automatically detects the cognitive level of students. The system is currently in the stage of further development.

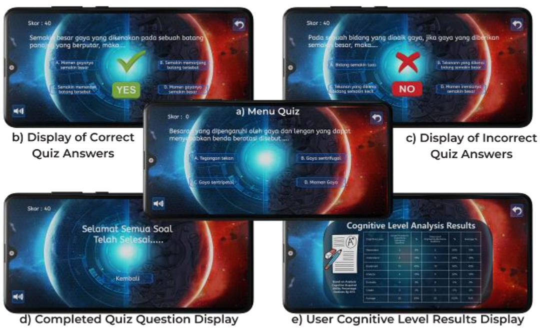

Fig 7. Quiz menu display and cognitive level analysis results.

E. Results of Validation, Revision, and Practicality Tests

Answer for RQ2: results of the validity and practicality of augmented reality in learning engineering mechanics?

The validation test results for a mobile application based on AR were assessed using focus group discussions and questionnaires distributed via Google Forms. Nine experts, including three from each field, validated the results by evaluating them in terms of media, material, and language. The generated application was evaluated, and the following are the findings:

Table 2 presents the average for the learning design aspect as 91.67%, the material aspect as 91.11%, and the quality of the learning aspect as 82.67%. The assessment results from all aspects obtained an overall average of 88.48% with the category "very valid." Comments and suggestions provided by the validator are material in the application to discuss the effectiveness of engineering mechanics in more detail.

Table 2. Expert validation results for the material

Aspect Assessment	V1	V2	V3	Avg. (%)	Criteria
Learning Design	87.50	90.00	97.50	91.67	very valid
Material Presentation	90.00	93.33	90.00	91.11	very valid
Quality of Learning	88.00	80.00	80.00	82.67	very valid
Overall Average				88.48	very valid

Media expert validation assesses and evaluates the development of applications on augmented reality content. The evaluation results of the developed media aspects shown in Table 3 indicate that the average value of the user interface quality aspect is 88.89%, the average value of the navigation software aspect is 90.56%, and the average interactive and communicative aspect is 88.33%. The assessment results of all aspects obtained an overall average of 89.26% with the category "very valid". The validator's Comments and suggestions are that the application writing should use bright colours and have a storage capacity below 100 MB.

Table 3. Expert validation results for the media

Aspect Assessment	V1	V2	V3	Avg.(%)	Criteria
User Interface Quality	93.33	86.67	86.67	88.89	very valid
Software Navigation	93.33	91.67	86.67	90.56	very valid
Interactive and Communicative	85.00	95.00	85.00	88.33	very valid
Overall Average				89.26	very valid

In determining the accuracy of English and Indonesian grammar in the application, the results of linguist validation evaluate spelling, grammar, and vocabulary. The results of linguist validation are shown in Table 4, the language validation results for the three assessment aspects. The average for the user language in this matter is 84.44%, the communicative aspect of language is 84.45%, and the media guide language aspect is 93.33%. The assessment results for all aspects obtained an overall average of 87.41%, a very valid category. Some grammar and spelling mistakes must be revised based on the validators' comments and suggestions.

Table 4. Expert validation results for the language

Aspect Assessment	V1	V2	V3	Avg.(%)	Criteria
Language in Matter	73.33	93.33	86.67	84.44	very valid
Communicative Language	80.00	86.67	86.67	84.45	very valid
Media Guide Language	90.00	90.00	100.00	93.33	very valid
Overall Average				87.41	very valid

Mobile Augmented Reality application that has successfully gone through the validation test process of material, media, and language aspects and has been revised based on comments and suggestions from validators. Furthermore, it will be evaluated based on the ease of use of the media used by lecturers as teachers and students who take part in learning engineering mechanics. The practicality test from the responses of lecturers and students was assessed based on the following aspects: visual media display, learning presentation, ease of media use, and learning benefits are presented in Table 5.

Table 5. Practicality test results of engineering mechanics-AR application

Aspect Assessment	Lecturer Response		Students Response	
	Avg.(%)	Criteria	Avg.(%)	Criteria
Visual Media Display	94.45	Very practical	80.16	Practical
Presentation of the Learning	86.67	Very practical	80.92	Practical
Ease of Media Use	84.33	Practical	83.30	Practical
Learning Benefits	93.33	Very practical	82.14	Practical
Overall Average	89.70	Very practical	81.63	Practical

Based on the results of the practicality test, the average overall assessment of lecturers' responses was 89.70% (very practical), and the average assessment of students' responses was 81.63% (practical). Thus, the findings show that mobile AR applications are practicable for face-to-face and distance learning, making this media a solution and an alternative to 21st-century learning.

Research on the development of mobile Augmented Reality as an emerging technology does not entirely rule out the possibility of the learning process offline and online, which refers to the Independent Campus curriculum with the competencies and skills to be achieved based on the semester learning plan. An android application that is stand-alone, self-contained, self-instructional, adaptive, and user-friendly facilitates an interactive, creative, and innovative learning process. This application creates a 360-degree reality experience that allows students to participate in learning actively. Consequently, the increase in student interest and motivation to learn indicates the success of the lecture process during one semester.

F. Discussion

Findings of previous research [52, 53] on learning media for engineering mechanics courses developed the e-module media stage and learning videos. A research paper submitted by [54] explained freeform classroom-based engineering mechanics learning tools that emphasise open interactive discussion models with actual events. According to a research paper [55], engineering mechanics instructional media aims to train digital literacy skills using an e-book development model as an alternative means in the COVID-19 pandemic. Based on several similar research references in developing engineering mechanics learning media, researchers conducted development research on mobile AR applications using devices with novelty in publications that have not been widely discovered and developed. Therefore, this is a new opportunity and solution for researchers in advancing AR technology as an interactive media in the engineering mechanics course of the Department of Mechanical Engineering [56, 57].

The integration of Augmented Reality is demonstrated in a video simulation, accessed at the following link: bit.ly/ApplicationSimulationVideos. 3D object animation is displayed in real-time without an internet connection when the user runs an application that directs the camera at marker-based tracking. The results show 3D objects on the material, motion force, moment of force, vector, rigid body equilibrium, and machine rod frame structure, as well as animation simulations with back sound and description panels to create a model for learning 21st-century skills. Another advantage provided by mobile AR applications is that they save the budget from the use of consumables in face-to-face learning with the development produced in the form of applications making it easy for users to access learning independently; this is a progress for universities as educational institutions following the technological trends in 21st-century education [58].

IV. Conclusion

This research results in an augmented reality mobile application with novelty in publications that have not been widely developed by presenting practical simulations and 3D object interactions in engineering mechanics learning. The results of this learning media development are the main features of AR in the form of 3D object visualisation and the supporting features of educational videos and e-modules that encourage independent learning motivation. The research team successfully developed a mobile AR application validated by material, media, and language experts with validity values of 88.48%, 89.26%, and 87.41%, respectively, with very valid categories. The level of practicality obtained from the lecturer's response was 87.70% for the very practical category and 81.63% for the student's response for the practical category. Therefore, the following conclusion was obtained in answering the research objectives: with the results of developing stable, responsive applications that perform well on user mobile devices, validity and practicality tests are declared valid and practical and suitable for learning engineering mechanics.

The presence of AR-based learning media is an opportunity for the nation's next generation to become agents of change to improve the level of education and teaching based on renewable technology in Indonesia. However, this research is limited to the validity and practicality of test stages for lecturers and students, and further research is targeted to apply the application to the effectiveness of the test and evaluate the learning of engineering mechanics as a whole. This research has implications for increasing student interest and motivation in applying digital technology in educational aspects by the demands of the Independent Campus curriculum, which is flexible, practical, interactive, and follows the competency needs of 21st-century skills.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All researchers contributed to this study. W. Waskito and A. Fortuna conducted the research and wrote the paper. R. E. Wulansari and R. A. Nabawi analysed the data and checked the data as a whole, F. Prasetya and A. Lutfi reviewed and finalised the manuscript. All authors have accepted the final version.

REFERENCES

[1] (2019). *The Promise of Education in Indonesia : Consultation Edition: Overview (English)*. [Online]. Available: http://documents.worldbank.org/curated/en/968281574095251918
[2] S. Yuliani and D. Hartanto, "Quality education for sustainable development in Indonesia," *Charting a Sustainable Future of ASEAN in Business and Social Sciences*, pp. 145–155, 2020. https://doi.org/10.1007/978-981-15-3859-9_14
[3] E. L. Damanik, "Blended learning: An innovative approach on social sciences at Indonesian higher education," *Education Quarterly Reviews*, vol. 3, no. 1, pp. 52–65, 2020. https://doi.org/10.31014/aior.1993.03.01.117
[4] S. Sulaiman, A. Imran, B. A. Hidayat, S. Mashuri, R. Reslawati, and F. Fakhrurrazi, "Moderation religion in the era society 5.0 and multicultural society," *Linguistics and Culture Review*, vol. 6, no. 1, pp. 180–193, 2022. https://doi.org/10.21744/lingcure.v6ns5.2106
[5] R. Wahyuningtyas, G. Disastra, and R. Rismayani, "Toward cooperative competitiveness for community development in Economic Society 5.0," *Journal of Enterprising Communities*, vol. 16, no. 1, pp. 1–27, 2022. https://doi.org/10.1108/JEC-10-2021-0149
[6] D. Nayyar, "Industrialization in developing Asia since 1970: Why technology, learning, and innovation matter," *Innovation and Development*, vol. 11, no. 2–3, pp. 365–385, 2021. https://doi.org/10.1080/2157930X.2021.1985696
[7] S. K. Ragamustari, N. B. Parwanto, A. A. Nawir, and E. Sukara, "Indonesia's science and technology capacity evolution dynamics from 1970 to 2018 compared to the Republic of Korea," *Innovation and Development*, vol. 13, no. 1, pp. 153–172, 2021. https://doi.org/10.1080/2157930X.2021.1928820
[8] T. Park and J. youn Kim, "An exploratory study on innovation policy in eight Asian countries," *Journal of Science and Technology Policy Management*, vol. 13, no. 2, pp. 267–297, Jun. 2022. https://doi.org/10.1108/JSTPM-03-2021-0036/FULL/XML
[9] T. Zhang, Z. A. Shaikh, A. V. Yumashev, and M. Chład, "Applied model of e-learning in the framework of education for sustainable development," *Sustainability (Switzerland)*, vol. 12, no. 16, pp. 1–15, 2020. https://doi.org/10.3390/SU12166420
[10] D. Vrontis, M. Christofi, V. Pereira, S. Tarba, A. Makrides, and E. Trichina, "Artificial intelligence, robotics, advanced technologies and human resource management: A systematic review," *International Journal of Human Resource Management*, vol. 33, no. 6, pp. 1237–1266, 2022. https://doi.org/10.1080/09585192.2020.1871398
[11] A. Szymkowiak, B. Melović, M. Dabić, K. Jeganathan, and G. S. Kundi, "Information technology and Gen Z: The role of teachers, the internet, and technology in the education of young people," *Technology in Society*, vol. 65, no. 1, 101565, 2021. https://doi.org/10.1016/j.techsoc.2021.101565
[12] K. Piwowar-Sulej, "Human resources development as an element of sustainable HRM—with the focus on production engineers," *Journal of Cleaner Production*, vol. 278, 124008, 2021. https://doi.org/10.1016/j.jclepro.2020.124008
[13] C. J. Mamahit, "Blended model of distance learning: Does it effective?" *Jurnal Pendidikan Teknologi Kejuruan*, vol. 3, no. 4, pp. 176–186, 2021. https://doi.org/10.24036/jptk.v3i4.15223
[14] A. Yakin, Muthmainnah, S. Ganguli, L. Cardoso, and A. Asrifan, "Cybersocialization through Smart Digital Classroom Management (SDCM) as a pedagogical innovation of 'Merdeka Belajar Kampus Merdeka (MBKM)' curriculum," *Digital Learning based Education*, pp. 39–61, 2023. https://doi.org/10.1007/978-981-19-8967-4_3
[15] Syahril, Purwantono, R. E. Wulansari, R. A. Nabawi, D. Safitri, and T. T. Kiong, "The effectiveness of project-based learning on 4Cs skills of vocational students in higher education," *Journal of Technical Education and Training*, vol. 14, no. 3, pp. 29–37, 2022. https://doi.org/10.30880/jtet.2022.14.03.003
[16] F. Prasetya, B. Syahri, B. R. Fajri, R. E. Wulansari, and A. Fortuna, "Utilizing virtual laboratory to improve CNC distance learning of vocational students at higher education," *TEM Journal*, vol. 12, no. 3, pp. 1506–1518, 2023. https://doi.org/10.18421/TEM123-31
[17] Z. Zakiyyah, M. D. Cahyani, and N. Fatnah, "Readiness of the science education study program in the implementation of the 'Merdeka Belajar - Kampus Merdeka' (MBKM) curriculum," *Scientiae Educatia: Jurnal Pendidikan Sains*, vol. 10, no. 2, p. 160, 2021. https://doi.org/10.24235/sc.educatia.v10i2.9243
[18] R. Hidayat, K. Kusen, and E. Risdianto, "Web-based cyber counselling system in supporting the implementation of the 'Merdeka Belajar-Kampus Merdeka (MBKM)' curriculum in university," *KONSELI: Jurnal Bimbingan dan Konseling*, vol. 9, no. 2, pp. 237–242, 2022. http://doi.org/10.24042/kons.v9i2.13518
[19] M. I. Odo, "Managerial techniques required of principals of technical and vocational colleges for quality assurance and skill acquisition," *Jurnal Pendidikan Teknologi Kejuruan*, vol. 6, no. 1, pp. 9–17, 2023. https://doi.org/10.24036/jptk.v6i1.28523
[20] R. Mursid, A. H. Saragih, and R. Hartono, "The effect of the blended project-based learning model and creative thinking ability on engineering students' learning outcomes," *International Journal of Education in Mathematics, Science and Technology*, vol. 10, no. 1, pp. 218–235, 2022. https://doi.org/10.46328/ijemst.2244
[21] N. B. Acedillo and J. M. Saro, "Students' lack of interest, motivation in learning, and classroom participation: How to motivate them?" *Psychology and Education: A Multidisciplinary Journal*, vol. 7, no. 8, pp. 636–645, 2023. https://doi.org/10.5281/zenodo.7749977
[22] M. D. B. Castro and G. M. Tumibay, "A literature review: Efficacy of online learning courses for higher education institution using meta-analysis," *Education and Information Technologies*, vol. 26, no. 2, pp. 1367–1385, 2021. https://doi.org/10.1007/S10639-019-10027-Z/METRICS
[23] S. Dhawan, "Online learning: A panacea in the time of COVID-19 crisis," *Journal of Educational Technology Systems*, vol. 49, no. 1, pp. 5–22, 2020. https://doi.org/10.1177/0047239520934018
[24] N. Jalinus, S. Haq, and G. K. Kassymova, "Work-based learning for the engineering field in vocational education : Understanding concepts , principles and best practices," *Journal of Engineering Researcher and Lecturer*, vol. 2, no. 1, pp. 9–17, 2023. https://doi.org/10.58712/jerel.v2i1.22
[25] R. S. Al-Fodeh *et al.*, "Quality, effectiveness and outcome of blended learning in dental education during the COVID pandemic: Prospects of a post-pandemic implementation," *Education Sciences*, vol. 11, no. 12, pp. 1–19, 2021. https://doi.org/10.3390/educsci11120810
[26] A. D. Samala and M. Amanda, "Immersive Learning Experience Design (ILXD): Augmented reality mobile application for placing and interacting with 3D learning objects in engineering education," *International Journal of Interactive Mobile Technologies*, vol. 17, no. 5, pp. 22–35, 2023. https://doi.org/10.3991/ijim.v17i05.37067
[27] C. B. De Lima, S. Walton, and T. Owen, "A critical outlook at augmented reality and its adoption in education," *Computers and Education Open*, vol. 3, 100103, 2022. https://doi.org/10.1016/j.caeo.2022.100103
[28] G. Lampropoulos, E. Keramopoulos, K. Diamantaras, and G. Evangelidis, "Augmented reality and gamification in education: A systematic literature review of research, applications, and empirical studies," *Applied Sciences (Switzerland)*, vol. 12, no. 13, pp. 1–43, 2022. https://doi.org/10.3390/app12136809
[29] J. Garzón, Kinshuk, S. Baldiris, J. Gutiérrez, and J. Pavón, "How do pedagogical approaches affect the impact of augmented reality on education? A meta-analysis and research synthesis," *Educational Research Review*, vol. 31, 100334, 2020. https://doi.org/10.1016/j.edurev.2020.100334
[30] J. W. Lai and K. H. Cheong, "Educational opportunities and challenges in augmented reality: Featuring implementations in physics education," *IEEE Access*, vol. 10, pp. 43143–43158, 2022. https://doi.org/10.1109/ACCESS.2022.3166478
[31] I. Radu, J. Yuan, X. Huang, and B. Schneider, "Charting opportunities and guidelines for augmented reality in makerspaces through prototyping and co-design research," *Computers & Education: X Reality*, vol. 2, 100008, 2023. https://doi.org/10.1016/j.cexr.2023.100008
[32] Nurhayati, Rusdi, and H. Isfaeni, "The application of mobile augmented reality to improve learning outcomes in senior high schools," *International Journal of Information and Education Technology*, vol. 12, no. 7, pp. 691–695, 2022. https://doi.org/10.18178/ijiet.2022.12.7.1672
[33] D. Roopa, R. Prabha, and G. A. Senthil, "Revolutionizing education system with interactive augmented reality for quality education," *Materials Today: Proceedings*, Elsevier Ltd, 2020, pp. 3860–3863. https://doi.org/10.1016/j.matpr.2021.02.294
[34] A. Ożadowicz, "Modified blended learning in engineering higher education during the COVID-19 lockdown-building automation courses case study," *Education Sciences*, vol. 10, no. 10, pp. 1–20, 2020. https://doi.org/10.3390/educsci10100292
[35] S. Saikat, J. S. Dhillon, W. F. W. Ahmad, and R. A. Jamaluddin, "A systematic review of the benefits and challenges of mobile learning during the covid-19 pandemic," *Education Sciences*, vol. 11, no. 9, pp. 1–14, 2021. https://doi.org/10.3390/educsci11090459
[36] S. F. Persada *et al.*, "How the education industries react to synchronous and asynchronous learning in COVID-19: Multigroup analysis insights

for future online education," *Sustainability (Switzerland)*, vol. 14, no. 22, pp. 1–21, 2022. https://doi.org/10.3390/su142215288
[37] P. L. C. Lam and H. K. Y. Ng, "Teaching and learning with mobile technologies under COVID-19 pandemic: Crisis or opportunity," *International Journal of Mobile Learning and Organisation*, vol. 17, no. 1/2, p. 198, 2023. https://doi.org/10.1504/IJMLO.2023.128359
[38] R. Hidayat and Y. Wardat, "A systematic review of augmented reality in science, technology, engineering and mathematics education," *Education and Information Technologies*, vol. 28, no. 9, pp. 1–26, 2023. https://doi.org/10.1007/s10639-023-12157-x
[39] P. Soltani and A. H. P. Morice, "Augmented realit y tools for sports education and training," *Computers and Education*, vol. 155, 103923, 2020. https://doi.org/10.1016/j.compedu.2020.103923
[40] A. Marini *et al.*, "Mobile augmented reality learning media with metaverse to improve student learning outcomes in science class," *International Journal of Interactive Mobile Technologies*, vol. 16, no. 7, pp. 99–115, 2022. https://doi.org/10.3991/ijim.v16i07.25727
[41] A. Fortuna, W. Waskito, P. Purwantono, A. Kurniawan, W. Andriani, and M. Alimin, "Designing learning media using augmented reality for engineering mechanics course," *Journal of Engineering Researcher and Lecturer*, vol. 2, no. 1, pp. 18–27, 2023. https://doi.org/10.58712/jerel.v2i1.20
[42] S. Radosavljevic, V. Radosavljevic, and B. Grgurovic, "The potential of implementing augmented reality into vocational higher education through mobile learning," *Interactive Learning Environments*, vol. 28, no. 4, pp. 404–418, 2020. https://doi.org/10.1080/10494820.2018.1528286
[43] Y. Wahyu, I. W. Suastra, I. W. Sadia, and N. K. Suarni, "The effectiveness of mobile augmented reality assisted STEM-based learning on scientific literacy and students' achievement," *International Journal of Instruction*, vol. 13, no. 3, pp. 343–356, 2020. https://doi.org/10.29333/iji.2020.13324a
[44] S. E. Smaldino, D. L. Lowther, C. Mims, and J. D. Russell, "Instructional technology and media for learning 12th Edition," *Pearson Education, Inc.*, New York, 2019, pp. 1–250.
[45] G. Lei, "Influence of ASSURE model in enhancing educational technology," *Interactive Learning Environments*, vol. 31, no. 1, pp. 1–17, 2023. https://doi.org/10.1080/10494820.2023.2172047
[46] N. Nieveen, "Prototyping to reach product quality," *Design Approaches and Tools in Education and Training*, Springer, Dordrecht, 1999, pp. 125–135. https://doi.org/10.1007/978-94-011-4255-7_10
[47] S. Syahril, R. A. Nabawi, and D. Safitri, "Students' perceptions of the project based on the potential of their region: A project-based learning implementation," *Journal of Technology and Science Education*, vol. 11, no. 2, pp. 295–314, 2021. https://doi.org/10.3926/JOTSE.1153
[48] E. Fernández-Gómez, A. Martín-Salvador, T. Luque-Vara, M. A. Sánchez-Ojeda, S. Navarro-Prado, and C. Enrique-Mirón, "Content validation through expert judgement of an instrument on the nutritional knowledge, beliefs, and habits of pregnant women," *Nutrients*, vol. 12, no. 4, pp. 1–13, 2020. https://doi.org/10.3390/nu12041136
[49] S. Cai, E. Liu, Y. Shen, C. Liu, S. Li, and Y. Shen, "Probability learning in mathematics using augmented reality: impact on student's learning gains and attitudes," *Interactive Learning Environments*, vol. 28, no. 5, pp. 560–573, 2019. https://doi.org/10.1080/10494820.2019.1696839
[50] R. Hakiki, M. Muchson, O. Sulistina, and A. Febriana, "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*, vol. 16, no. 4, pp. 70–84, 2022. https://doi.org/10.3991/ijim.v16i04.28989
[51] A. T. Devega, A. Ambiyar, P. Panyahuti, N. H. Adi, and A. R. Riyanda, "The effectiveness of learning media on the outcome of computer and basic network of vocational students," *Jurnal Pendidikan Teknologi Kejuruan*, vol. 5, no. 2, pp. 47–52, 2022. https://doi.org/10.24036/jptk.v5i2.23123
[52] D. Nurhadiyanto, M. F. Widiyastuti, and H. Pratiwi, "The influence of improved engineering mechanic module in vocational high school," *Journal of Physics: Conference Series*, 2020. https://doi.org/10.1088/1742-6596/1446/1/012024
[53] H. Tambunan and E. Napitupulu, "Effectiveness of interactive multimedia based learning model in engineering mechanics," *International Education Studies*, vol. 9, no. 10, p. 155, 2016. https://doi.org/10.5539/ies.v9n10p155
[54] J. F. Rhoads, E. Nauman, B. M. Holloway, and C. M. Krousgrill, "The purdue mechanics freeform classroom: A new approach to engineering mechanics education," *ASEE Annual Conference and Exposition, Conference Proceedings*, 2014, p. 24.1241.5. https://doi.org/10.18260/1-2--23174
[55] A. Ravi, B. Ses, E. Polonia, P. N. Ketapang, and W. Borneo, "The use of EMB (Engineering Mechanics Book) mobile app to train students' digital literacy skills during COVID-19 pandemic," *Tarbiyah: Jurnal Ilmiah Kependidikan*, vol. 10, no. 2, pp. 103–114, 2021. https://doi.org/10.18592/tarbiyah.v10i2.5542
[56] J. Buchner, K. Buntins, and M. Kerres, "The impact of augmented reality on cognitive load and performance: A systematic review," *Journal of Computer Assisted Learning*, vol. 38, no. 1, pp. 285–303, 2022. https://doi.org/10.1111/jcal.12617
[57] M. Vásquez-Carbonell, "A systematic literature review of augmented reality in engineering education: Hardware, software, student motivation & development recommendations," *Digital Education Review*, no. 41, pp. 249–267, 2022. https://doi.org/10.1344/DER.2022.41.249-267
[58] D. R. Rizaldi, E. Nurhayati, and Z. Fatimah, "The correlation of digital literation and STEM integration to improve indonesian students' skills in 21st century," *International Journal of Asian Education*, vol. 1, no. 2, pp. 73–80, 2020. https://doi.org/10.46966/ijae.v1i2.36