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Leveraging Marker-based Augmented Reality to Enhance Simplified Representation Learning in Mechanical Drawing : A Practical Studies in The Mechanical Engineering Curriculum

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Abstract: This study aims to develop AR technology of simplified representations based on ISO standards and to quantify the efficiency and contribution of developed AR technology in assisting students in learning mechanical drawing. This research proposed a marker-based AR application development, intended for teaching simplified representations, named Augmented Reality Penyederhanaan Gambar - ARPeGa, and an experimental study to quantify the user experience (UX) using the User Experience Questionnaire (UEQ). A pilot study involving 38 mechanical engineering students was conducted to evaluate the impact of AR involvement on user experience. In addition, the UEQ data analysis tool version 11 was used. The UEQ results showed attractiveness was excellent (1.87), while efficiency, dependability, stimulation, and novelty were good (1.63, 1.60, 1.63, and 1.22 respectively). And perspicuity was categorized as "above average" (1.51). This study's outcomes demonstrate that using 3D model visualization in the AR application strengthens user experiences to understand simplified representations. Overall, the application has a 'good' level in some categories: efficiency, dependability, stimulation, and novelty.

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Introduction

In the current industrial revolution, all countries are competing to innovate development technology, one example of which is the development of augmented reality technology. This technology has contributed to human life in various fields. Augmented reality (AR) is defined as a merging of real and virtual things in a real environment that operates interactively in real-time, and there is integration between items in 3D, specifically virtual objects incorporated into the real world (Qiao et al., 2019). Augmented Reality is a part of multimedia-based technology that can have the ability to describe a situation and also an object that can be viewed from various points of view because this technology adapts the ability of 3D visualization. Regarding its potential advantages, these technological applications have been explored in education, especially for teaching and learning (Wu, Lee, Chang, & Liang, 2013; Sabrina et al.,2022).

Augmented Reality (AR) can be used on mobile devices that most people have. The current version of the mobile device operating system supports the use of AR. Marker-based tracking is a method in AR that has a picture as a medium that plays a role in showing virtual objects on it. The marker will be recognized by augmented reality applications that have included augmented reality technology through camera vision devices by recognizing the position and the orientation of the marker in the 3 axes: X, Y, and Z (Wagner & Schmalstieg,

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2009). Markers are used so that the camera knows what to look for while employing image recognition and to calculate the posture of a 3D model in real time (Siltanen, 2012).

On the other hand, mechanical drawing is a basic subject in the mechanical engineering curriculum which delivers visual communication tools used among mechanical engineers (Shen & Lu, 2021). Mechanical drawing is used to illustrate the actual physical components on a 2 dimensional-drawing piece of drawing paper. The mechanical drawing contains not only geometry and dimension, but also information of material, tolerances, and other necessary manufacturing information. One of the topics taught in mechanical drawing is a simplified representation which is commonly used to simplify complex geometries of mechanical components using symbols and drafting conventions, so engineers still understand the drawing (Wang & Cheng, 2014). This simplified representation significantly minimizes drafting time and enables more efficient work. Moreover, symbols and conventions used in simplified representation have been managed by the International Organization for Standardization (ISO). Some simplified representations of mechanical parts follow conventions as follows: springs based on ISO 2162-1:2016 (ISO, 2016), holes ISO 15786: 2008 (ISO, 2008), fasteners in ISO 225: 2010 (ISO, 2010a), screws in ISO 6410-3: 2010 (ISO, 2010b), bearings in ISO8826-2:1994 (ISO, 1994), pipe or duct in ISO 6412:2017 (ISO, 2017), gears in ISO 2203: 1973 (ISO, 1973) and so on.

Related to mechanical drawing and augmented reality, some implementations have been discussed in previous works: An augmented Reality Tool (ART) was developed to improve student's spatial visualization competencies (Balak & Miman, 2020), an AR application used for teaching manual mechanical drawing (Horii & Miyajima, 2013) and an AR initiated for improving understanding of drawing in railway construction (Kim, Park, Han, & Kang, 2017). Similar work also presented SMELAR – Standard Mechanical Elements Learning through Augmented Reality which was developed to visualize mechanical components using a PC and webcam (Martín-Gutiérrez, 2011). Balak also developed an AR application to improve student skills in understanding orthogonal projection (Balak, Kisa, & Miman, 2018). Awuor developed a mobile AR that enables students to compare mechanical parts in a 3D model and its 3 views orthogonal projection then evaluated its use among vocational students (Awuor et al., 2022). In addition, AR applications were implemented in terms of training: machineries and operations (Alahakoon & Kulatunga, 2021; Hedenqvist, Romero, & Vinuesa, 2021; Scaravetti & François, 2021), and maintenance (M. Wang, Callaghan, Bernhardt, White, & Peña-Rios, 2018). Other works used markerless augmented reality and applied it in manufacturing and construction (Cheng, Wang, Tjondronegoro, & Song, 2018; Y. Wang, Zhang, Yang, He, & Bai, 2018). Numerous other studies of the research have shown encouraging trends and the beneficial effects of adopting AR in education (Akçayir & Akçayir, 2017; Chen, Liu, Cheng, & Huang, 2017).

However, there have been few attempts to use AR technology focusing on mechanical drawing but there are still limited applications discussed in distance learning outcomes. To overcome the problems that have been described, a maker-based augmented reality system is proposed as an educational tool that can provide accessible mechanical drawing content delivering simplified representations of mechanical components. Therefore, this study aims to develop AR technology of simplified representations based on ISO standards and to quantify the efficiency and contribution of AR technology in assisting students in learning mechanical drawing.

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Research Method

In the development process of the AR application for teaching simplified representation in mechanical drawing, it needs precise understanding to cover the topic. This study aims to develop an augmented reality application and to assess and quantify the user experience (UX) of the developed application. The research methodology is illustrated in Figure 1.

Augmented Reality Application Development

The proposed AR application is called ARPeGa (Augmented Reality Penyederhanaan Gambar). This AR is a marker-based augmented reality application. To comply with simplified representations, each mechanical component should be designed with 2 items: 3D model and its 2D simplified drawing of a part or component. Therefore, to develop the AR application, there are 6 stages as follows:

1). Making each 3D model of mechanical part (nut, bolt, gear, bearing, spring, etc).
2). Generate 3D model into 2D drawing.
3). Marker making and computer vision process in Vuforia SDK and Unity.
4). Making ARPeGa layout which covers a marker, simplified representation drawing, and 3D model isometric view.
5). Generate ARPeGa application APK (Android Package Kit) file format and test it.
6). Deployment ARPeGa into android playstore.

In detail, related to application development, after reviewing some ISO standards for certain mechanical components such as nuts, bolts, gears, springs, screws, studs, and bearings, they have been built in 3D models with 3D CAD (Computer-aided Design) Solidworks and simply drawn in 2D mechanical drawing. The implementation methodology starts with making 3D model of those components. Then, component's 2D mechanical drawings were generated from the 3D model and printed in ARPeGa layout. On the other hand, 3D models also need to be converted to FBX file format which then would be processed in Vuforia SDK and Unity with configured markers. The application of ARPeGa test bed then was done to have a proper and working augmented reality application then deployed in Android Play Store.

Experimental Design

After completing the marker-based augmented reality application, an experimental design was set up for participants. The last stage is conducting a quantitative study of the developed application with a User Experience Questionnaire (UEQ) for getting user perceptions. The study respondents are 38 students in mechanical drawing classes (2nd semester) in our mechanical engineering department. To measure the quantitative value of the application user experience (UX), user feedback is required. The UEQ survey consisted of six numerical scales (1 to 7) into 26 indicator questions was performed using UEQ form and built-in automatic analysis. These measured various aspects are Attractiveness, Efficiency, Perspicuity, Dependability, Stimulation, and Novelty (Ahram & Falcão, 2017):

1) Attractiveness: The application should look attractive and impressive.
2) Efficiency: The users can perform their tasks well organized.
3) Perspicuity: The application should be easy to understand.
4) Dependability: The users feel in control of the interaction and meet their expectations.
5) Stimulation: The application should engage and motivate users to continue using it.
6) Novelty: The application should be innovative and creatively designed.

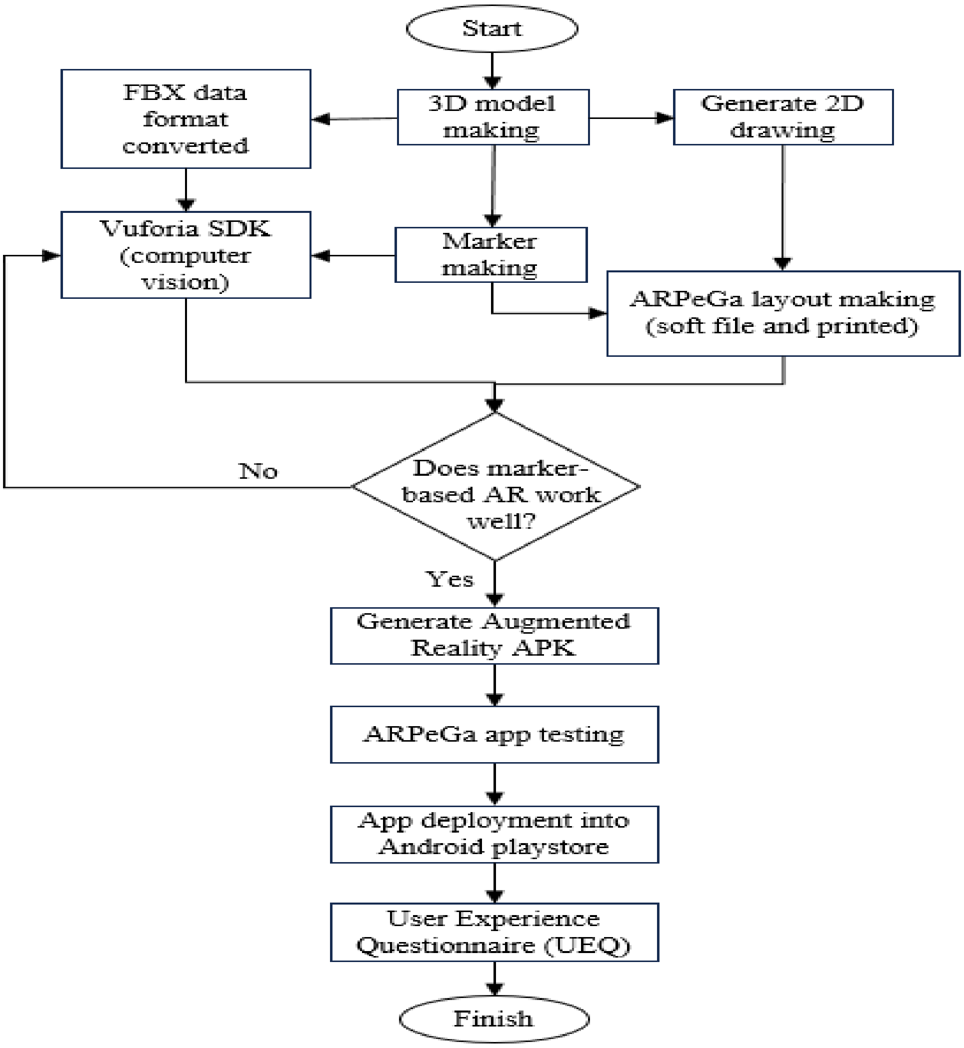

Figure 1. Research methodology flowchart

System Implementation of Augmented Reality

Tools and Technology

Unity and Vuforia SDK are the chosen SDK to develop the ARPeGa application. Vuforia SDK was selected for this application development due to the fact this platform affords Augmented reality SDK for image recognition to recognize the textual content, photo or barcode from the document. Inside the Vuforia account marker for ARPeGa application are stored for scanning. Unity 3D is the engine used for making the ARPeGa application. These developments were based on personal computers which had supported specifications. The result of the Unity3D engine is within the form of a phone application with Android operating system. Every image and animation in the ARPeGa menu are designed using Solidworks, FBX, and Unity. The FBX file formats are used for making the animation movement inside the application of the animation video to make the image rotate for better inspection. ARPeGa application turned into used inside the smartphone with a minimum specification for using the application around 2 GB RAM, 32 GB inner memory, 12 MP camera to hit upon the marker, and the Android 9.0 Operating System.

System Overview

The ARPeGa application is a mobile Augmented Reality application that needs to be run with 2D image layout using a scanner to make a 3D image display of the actual part in the

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application, which runs in a smartphone with Android OS platform. The User Interface inside the ARPeGa application shows multiple options to start using the application. It contains multiple buttons to start, the guidance button, 2D layout download button, the about button, and the exit button.

To start the ARPeGa application press the guidance button to read every step we need to operate the app it consists of multiple steps we need to do to make the app working properly. The first step is to download the file stored inside the app. The file consists of information about the 2D image, 3D models of the component, and the marker to scan the actual part. In the second step, we need to scan the marker on the file by pointing the camera on our phone to the marker so the image part can show up. The third step, observing the image part by changing its scale or rotating it to get the full description of the part. Those steps can be seen in the ARPeGa instruction in Figure 2.

Figure 2. AR Simplified representation use-instruction in Indonesian

Features Overview

In this study, there are two designs of the marker-based augmented reality to be synchronized, the ARPeGa application and the ARPeGa layout. Figure 3 shows an example page of the Augmented Reality Layout which contains the marker that is used for scanning the actual image part inside the ARPeGa application. In each layout, there is a simplified representation drawing of a mechanical component, its isometric view, and a marker. Figure 4 shows the menu interface inside the ARPeGa application. A user must download the layout before starting the ARPeGa application.

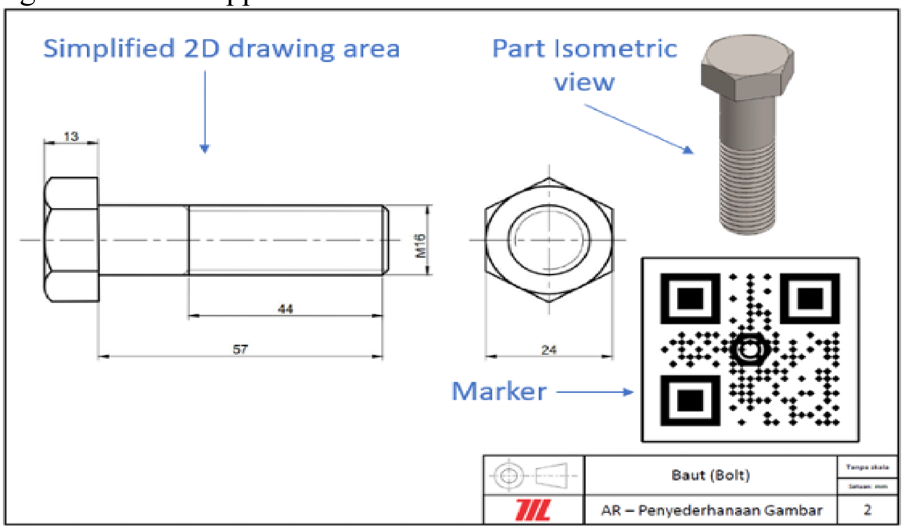

Figure 3. Example of ARPeGa printed layout with a marker

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Figure 4. User menu interface

Results and Discussion

Figure 5 shows an example of the ARPeGa application when the smartphone camera is set to scan the marker on the Augmented Reality Layout file. Animation of the image part are showing out after 5 seconds, and it shows automatically when the camera on the smartphone scans the marker. The figure also shows the image part of Augmented Reality that showing out when the user rotating and scaling the image for better view to the application users.

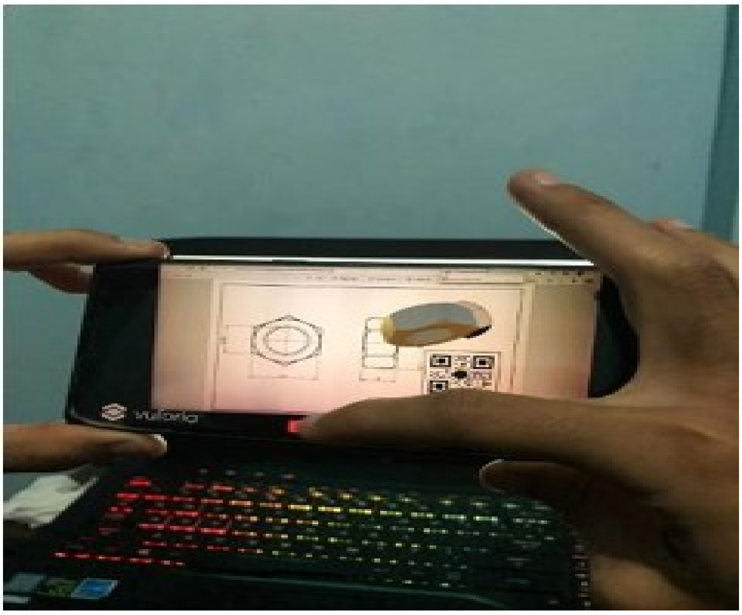

Figure 5. Simplified Representation AR in use

This study presents the application of marker-based augmented reality which is related to the manufacturing community, in particular mechanical drawing's teaching. This also emphasizes the importance of designing marker-based based augmented reality application to support teaching simplified representation as a part topic in mechanical drawing, named ARPeGa. The suitable application works well and can be downloaded in Android playstore, https://play.google.com/store/apps/details?id=com.ar.pega.

Testing

After finishing the ARPeGa application, an experimental study was conducted for mechanical engineering students who took a mechanical drawing course as participants. This testing phase was implemented to settle the application and to assess the efficacy of learning media. The participants for the testing phase were 38 mechanical engineering students. The overall age range of those students was 19-20 years. We also put the developed ARPeGa application through quantitative testing. To determine the quantitative value of the application interface, direct user feedback is required. The user experience questionnaire (UEQ) form and built-in automatic analysis were used to deliver the test. We used UEQ Data Analysis Tool Version 11 and Microsoft Excel.

User Experience Questionnaire (UEQ)

In this study, we conducted a UEQ questionnaire using the online platform https://easy feedback.com, and it was distributed to the participants. The students who participated in this study have tried the application and filled out the UEQ form on a smartphone, tablet, or personal computer. The UEQ assessment was distributed into 26 questions and classified them into 6 UEQ categories: attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. Through this study, the utility measurements were carried out to determine the level of perception of the users in using the ARPeGa application. And the table 1 presents the UEQ result of ARPeGa application. The confidence interval is a measured value for the accuracy of the average scale. A narrower confidence interval indicates a more accurate estimate. And width of confidence interval depends on data availability and consistency in product evaluations (Derisma & Hersyah, 2021). Based on Figure 6, the results of all UEQ scales Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty, which were evaluated post-testing, were found to be sufficient with scores between +1 and +2. Based on the graph's small interval lines, the sample data supports population ranges even though with multiple trial evaluations.

Table 1. Scale result of ARPeGa application

Scale	Mean	Std. Dev.	N	Confidence	Confidence Interval	
Attractiveness	1.87	0.88	38	0.28	1.59	2.15
Perspicuity	1.51	0.89	38	0.28	1.23	1.80
Efficiency	1.63	1.06	38	0.34	1.29	1.97
Dependability	1.60	1.01	38	0.32	1.28	1.92
Stimulation	1.63	1.10	38	0.35	1.27	1.98
Novelty	1.22	1.06	38	0.34	0.88	1.55

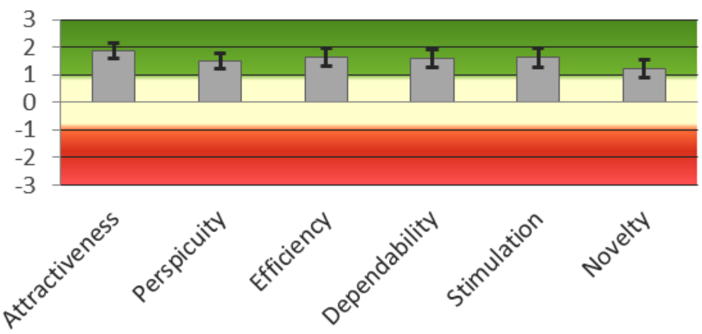

Figure 6. Confidence interval of category scales in UEQ

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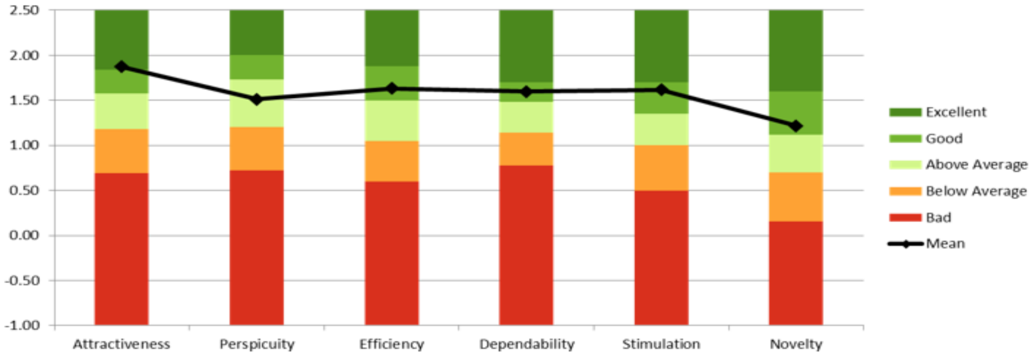

Figure 7. UEQ result of ARPeGa application

Figure 7 illustrates the result of the ARPeGa application. It can be seen that the highest value is the attractiveness category, the 'excellent' level. This means developed AR application is able to attract users to enjoy using the app interactively and to learn simplified representation in the subject of mechanical drawing. The next 4 categories, namely: efficiency, dependability, stimulation, and novelty in ARPeGa application were at the 'good' level. For the 4 elements at the 'good' level, means that the users can learn quickly using the application and meet their expectations. Moreover, the users felt the ARPeGa application is an innovative and supportive learning media. Perspicuity was at the 'above average' level. In the perspicuity or clarity category, the application can be easily understood by the user.

The UEQ instrument includes benchmark data from 468 studies concerning different products (Schrepp, 2023). From Figure 7, The developed application was categorized as an "Excellent" scale in the attractiveness category, this indicates that the application is in the range of the 10% best results. The application is labeled as "Good" level in Efficiency, Dependability, Stimulation, and Novelty which means 10% of the results in the benchmark data set are better and 75% of the results are worse. The Perspicuity is rated as an "Above Average" scale which indicates 25% of the results in the benchmark are better than the result for the evaluated product, and 50% of the results are worse. Based on the user's perceptions after giving feedback conducted the UEQ method, have implied that the ARPeGa as a marker-based augmented reality application was developed to enhance students' skills to understand the subject of simplified representation in mechanical drawing subject.

Conclusion

Based on the results, this study discussed the application development of ARPeGa. The application works well and has been already deployed in the Android Play Store. In general, the UEQ values of the ARPeGa application were in the 'above average' to 'excellent' range. The results showed that the students were interested and easily understood the way in experiencing the Augmented Reality for simplified representation. Overall, the application has a 'good' level in some categories: efficiency, dependability, stimulation, and novelty.

Recommendation

Researchers can conduct further studies to add various mechanical components and interactive buttons to the learning tool to increase students' knowledge. Other lecturers and teachers who run the mechanical drawing class and its practicum, should try and examine the usefulness and impact of this learning tool for teaching their students.

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application development. This publication is an extended study to evaluate the developed application run in mechanical drawing classes.

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