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Developing a Learning Design with Augmented Reality to Improve Critical Thinking and Problem-Solving Skill

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ABSTRACT

This research was conducted to develop and evaluate learning design using Augmented Reality (AR), which aims to improve critical thinking and problem-solving skills in basic turning topics. Methodology – The learning design was developed using Design-Based Research (DBR), with process stages: preliminary study, development, and evaluation. Literature review and instruments inform the learning design of teachers and student needs on basic learning to ensure students have the skills for practice. Part of the learning design, including modules and storyboards, is created to provide an overview of learning design outcomes. The learning design and storyboard are evaluated by learning design experts and mechanical engineering teachers. Findings – The result of the development learning design is feasible because it is needed based on the problem indicator points in the preliminary study activity. So, this learning design will be a reference for AR-based learning media. Significance – These findings indicate that learning is based on Augmented Reality (AR) and teaching that uses the PJBL model, and this must be fostered in machining engineering learning to increase students' success in making work steps for a product. This learning design helps teachers improve teaching and student learning in the classroom before practicing on real machines.

Introduction

The development of science and technology in the 4.0 era continues to encourage efforts to update the use of technology in the learning process to improve the quality of teaching. (Oztemel & Gursev, 2020) (Grodotzki et al., 2018). One of the most significant innovations in technical education is the integration of technology-based learning media 4.0, which must be aligned with learning contexts, technological advancements, and competency goals. Research on engineering education emphasizes that effective learning media should incorporate usability, engagement, sophistication, and interactivity while accommodating technological developments with robust features. Augmented Reality (AR) emerges as a promising learning medium in this context.

AR is a technology that transforms the virtual world with the real world (Pipattanasuk & Songsriwittaya, 2020). Virtual-based labs, including AR applications, provide students with enhanced accessibility, offering three-dimensional visualizations that replicate real-world learning environments (S. K. Wang et al., 2014) (Eisazadeh & Akundi, 2022). This research specifically explores the implementation of AR-based learning media in mechanical engineering education (Dede et al., 2019). Prior studies suggest that AR fosters greater student engagement and interaction with virtual-based practice tools, allowing them to explore and experiment without constraints. Additionally, AR enhances safety by minimizing direct exposure to hazardous machinery during training. The technology enables visualization of learning processes, reducing reliance on expensive physical equipment while improving academic outcomes (Dutta et al., 2022) (Purwaningtyas et al., 2022).

Furthermore, AR-based learning media contribute to the development of essential 21st-century skills, such as problem-solving (Lima et al., 2023) (Espejo-Peña & Flores-Osorio, 2023), critical thinking (Wells-Beede et al., 2022) (Demircioglu et al., 2022), communication (Hess et al., 2022) (Ryan et al., 2022), collaboration (Qing, 2022), and creativity (Grinshkun & Osipovskaya, 2020). These competencies are crucial for technical education, which demands practical skills aligned with industry requirements. However, several challenges persist in vocational education, including limited access to practice equipment, inadequate safe learning spaces (Concannon et al., 2019), and insufficient workplace safety training (Enzai et al., 2021). These constraints hinder skill development, emphasizing the need for innovative learning approaches, particularly through the use of Industry 4.0 technologies (Subiyantoro & Munif, 2022).

Despite its benefits, the justification for AR's superiority over traditional teaching methods beyond engagement remains underexplored. This study aims to address this gap by examining how

AR directly mitigates deficiencies in mechanical engineering education, such as limited hands-on experience and resource constraints.

Given these considerations, this research introduces a novel approach to machining education through AR-based learning designs. Machining courses necessitate proficiency in planning, operating machinery, and adjusting tools—foundational skills crucial for students' technical development. However, challenges such as inadequate practical sessions, limited instructional time, and a shortage of functional machinery hinder effective learning. Open interviews with vocational teachers reveal that students are primarily exposed to theoretical instruction, with minimal hands-on practice before engaging in actual production. Observations at SMK Bandung highlight deficiencies in lathe equipment, with many machines being non-operational or unsafe due to damage. Overcrowded practice sessions further exacerbate the risk of equipment misuse and accidents (Monroy Reyes et al., 2016). The introduction of AR-based learning tools offers a viable solution by enabling students to engage in fundamental machining tasks independently, even without direct instructor supervision (Monroy Reyes et al., 2016).

Therefore, this study aims to develop an AR-integrated learning design for machining education to enhance critical thinking and problem-solving skills among 10th-grade vocational students. The research will be conducted in two phases: (1) a preliminary study to assess challenges in machine learning related to equipment availability and 21st-century skill development and (2) the design of AR-based instructional materials incorporating critical thinking and problem-solving approaches. Additionally, this study will explore the feasibility of AR adoption in vocational schools with varying levels of technological infrastructure, addressing potential barriers to large-scale implementation.

Method

The method used Design-Based Research (DBR). DBR has recently received considerable attention from researchers in the field of education as a new framework that can guide better educational research (Akker et al., 2006) (Brown, 1992) (Cobb et al., 2003). The purpose of DBR is to increase the impact and transfer of educational research and produce pragmatic and generalizable design principles (F. Wang & Hannafin, 2005). DBR has the following characteristics: (1) it is located in a real educational context, (2) it focuses on the design and testing of significant interventions, (3) it adopts mixed methods to provide better guidance for educational improvement, (4) involves multiple evaluations to achieve the best design, and (5) collaboration between researchers and practitioners (Anderson & Shattuck, 2012). DBR framework on figure 1 adapted from (Brown, 1992) Includes:

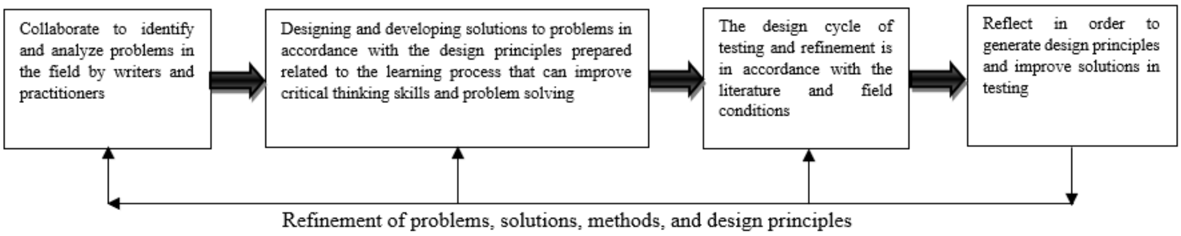

Fig 1: Stages of Design-Based Research

This study adapts the DBR framework from (Brown, 1992) which consists of four main stages that shown on table 1:

Table 1. DBR activity

DBR Framework	***Activity***
Problem analysis and exploration	➢ Identifying challenges in learning machining engineering practice in Bandung City and Regency Vocational Schools. ➢ Conduct preliminary studies through interviews and questionnaires with program heads, teachers, and students. ➢ Review related literature to understand best practices in technology-based learning design.
Initial solution design and development	➢ Designing a learning model for basic lathe engineering material with the support of AR. ➢ Develop learning design evaluation instruments based on theoretical studies and best practices. ➢ Conduct limited testing to identify initial weaknesses in the design.
Implementation and evaluation in real context	➢ Validate the design by two learning design experts. ➢ Learning design experts assess the feasibility of content based on certain criteria, such as suitability to learning needs, effectiveness in improving students' critical thinking and problem-solving skills, and integration of AR technology. ➢ Implement classroom learning design and collect data through observations, interviews, and questionnaires.
Design reflection and revision	➢ Analyze the results of the implementation to identify the strengths and weaknesses of the learning design. ➢ Revise the design based on feedback from students, teachers, and experts. ➢ Develop generalizable design principles for further development

Participant

This research involved teachers and students of machining engineering at SMK Kota and Bandung Regency. Participants were divided into two main groups, including 1) Preliminary study participants, 16 teachers from 16 machining engineering vocational schools, and 203 students who filled out a questionnaire related to the use of learning media, and 2) a Literature review team. The participants in the validation of the learning design are two learning design experts who have doctoral qualifications in the field of education, as well as teaching experience in learning models and educational technology. For expert judgment as well as two learning design experts.

Research Subject

The topic of this research is the basic material. This material is the initial material that students must understand before practicing with a lathe. This research includes 1) Designing AR-based learning to improve students' critical thinking and problem-solving skills, 2) Validation by learning design experts, and 3) Revision based on validation and implementation results.

Data Collection

Data were collected using Qualitative techniques, which combine several methods to obtain more comprehensive data. (Creswell, 2017). Data collection methods include:

1. Observation – Observing the completeness and feasibility of the practice tools.
2. Interview – An interview is conducted with the head of the study program to obtain information about the problem of workshop equipment, workshop feasibility, and the application of learning media in schools.
3. Documentation – to support information in the form of image evidence in terms of the feasibility and completeness of learning practice tools.
4. Literature Review – to find out research trends and the impact of the application of AR using Blibiometric Analysis (BA) and Systematic Literature Review (SLR) analysis.
5. Instrument Validation – Using instruments that have been validated by experts to assess the effectiveness of learning designs.

Result and Discussion

Problem analysis and exploration

Preliminary results on table 2 show that the lathe machine in the Vocational School workshop in the city and district of Bandung has varying levels of feasibility. Some schools have adequate facilities, but others still need improvement in terms of maintenance and availability of equipment.

The practical implication is that schools can consider integrating AR technology to overcome the limitations of physical equipment and provide a more comprehensive simulation experience for students (Suhail et al., 2024).

Table 2. Preliminary Study

Indicator	***Data Collection***	***Results***
Lathe Machine in the workshop Mechanical Engineering in City and Regency of Bandung	Interviews and Observations	The completeness of lathes in vocational education is produced by 81%. This data is based on the facilities and infrastructure standards in the lathe area; this value is the smallest of all indicators.
Feasibility of lathes in mechanical engineering in Bandung City and Regency	Interviews and Observations	The feasibility of lathes is 70%. This data is by the feasibility standards of facilities and infrastructure in the lathe area; this value is the smallest of all indicators.
Augmented Reality (AR) Research Trends	Data mining on the journal portal and visualized using VosViewer	These results show that most articles focus on mobile learning and virtual-based learning, and there is a novelty emerging in augmented reality research in technical education, namely technical education at the secondary education level. It can be seen that AR research in secondary education for the engineering field is still small; this emergence has existed since 2019.
Impact of Augmented Reality (AR)	Systematic Literature Review	1) Make student behavior close to average and academic decline because it attracts students to use modern technology in learning, such as mobile devices; 2) The design of Augmented Reality tools is more interactive and exciting, supporting distance learning activities such as online classes with virtual learning materials that cannot interact with students to get a better display of equipment, 3) overcome facility constraints, security concerns and to increase student interest in the teaching and learning process, 4) ease for teachers/instructors to implement media games as it has the potential to create a more flexible environment for classroom learning. However, the initial cost of setting up this technology is high; 5) AR development can facilitate versatile and continuous learning tools to operate active learning environments; 6) Augmented reality has characteristics corresponding to the current era of industrial revolution 4.0, 7) and they are eager to know about the developed AR system (Bendicho et al., 2017), (Kassim et al., 2019), (Enzai et al., 2021), (Kaur et al., 2022), (Solmaz et al., 2021), (Huda et al., 2021), (Tuli et al., 2022), (Dutta et al., 2022), (Purwaningtyas et al., 2022).
The Influence of AR Technology on 21st Century Skills	Data mining on the journal portal and visualized using VosViewer	AR technology was found to improve HOTS. The application of AR that can increase HOTS has occurred from 1997 to 2023. All of these skills need to be mastered by students because the application of 4C skills *(Creativity, Critical Thinking, Communication*, and Collaboration) can improve HOTS as a provision to face the challenges of the 21st century to be successful in the world of work (Fulla &; Scoot, 2014) and (Widiawati et al., 2018). It was found that those who can improve critical thinking skills are still few compared to others. So there is an opportunity to develop AR with a critical thinking skills approach that raises problem-solving because critical thinking has a connection with problem-solving
Teacher and Student Readiness in the Use of AR Learning Media	Questionnaire	This data explains teachers' perceptions of using learning media in turning materials. The results of the percentage produced, on average, 73%, which means that teachers often use learning media in delivering their material to students. So that teachers, if they develop learning media, are ready and can

Research trends show that the use of AR technology in engineering learning is increasing. Previous studies have shown that AR can improve students' conceptual understanding, practical skills, and learning motivation (Schiffeler et al., 2020) (Zoghi et al., 2018). In the context of education in vocational schools, the use of AR can help students understand basic concepts and machining techniques before interacting directly with physical machines. Several AR-based learning approaches have been developed just shown on table 3.

Table 3. Comparison of AR-Based Learning Approaches

Approach	***Description***	***Applications***	***Benefits***	***Source***
Projection-Based AR	Interactive 3D visualizations	Anatomy, Engineering	Enhances visualization and comprehension	(Shrestha et al., 2024)
Marker-Based AR	Detects physical markers to display digital content	Language Learning, Geography	Increases engagement and motivation	(Afnan et al., 2021)
Location-Based AR	Uses GPS for context-aware learning	History, Environmental Science	Provides immersive and contextual learning	(Vashisht & Sharma, 2024)
Application-Based AR	Simulates real-world scenarios	Medical, Engineering	Offers hands-on practice and improves understanding	(Cai et al., 2013) (Liu et al., 2024)

The approach used in this study is projection-based AR with HoloLens, which was chosen because it provides a more immersive experience than other methods. However, this approach also has challenges in terms of cost and accessibility of the device.

The results of the study show that the use of AR in machine engineering learning has a positive impact on the development of 21st-century skills, namely critical thinking which helps students be more active in analyzing and solving problems related to a lathe and problem solving, AR helps students understand machine mechanisms and accelerate the troubleshooting process (Kudale & Buktar, 2022) (Scaravetti & François, 2021). The core activities use DL and PjBL models, which have been proven effective in improving students' understanding and technical skills (Purwaningsih et al., 2020) (Sharma et al., 2020).

AR has several limitations that need to be considered that shown on table 4, including: 1) The cost and accessibility of devices such as HoloLens are still relatively expensive, so their adoption in vocational schools requires careful budget planning, 2) The importance of teacher training because not all teachers have technical skills in operating and developing AR content, so special training is needed, 3) Hardware limitations because not all schools have the infrastructure to support the use of AR optimally. Practical solutions to address these challenges that shown on table 4.

Table 4. Comparison of AR-Based Learning Approaches

Solution	***Description***	***Supporting Abstract***
Affordable AR Devices	Develop and utilize cost-effective AR devices and mobile integration	(Jerry & Jones, 2019)
Simplified AR-Based Curricula	Create user-friendly tools for AR content creation and integrate AR into existing curricula.	(Macariu et al., 2020)
Intensive Training for Teachers	Provide comprehensive training and ongoing support for teachers.	(Marín-Dia et al., 2023)

In interviews with several teachers and department heads, the majority agreed that students who are trained in using AR have an advantage in better conceptual understanding because students who are used to using AR have an easier time understanding the structure and mechanism of the machine before hands-on practice. Readiness to use modern technology in the manufacturing industry is increasingly adopting digital technology, and AR experiences help students adapt faster. By improving occupational safety with AR simulation, students can understand safety procedures before interacting with real machines. However, some industry professionals also note that hands-on experience is still necessary to complement AR-based learning. Therefore, the combination of AR-based learning and hands-on practice in the workshop remains the best approach to mechanical engineering.

Initial solution design and development

Learning Design

The learning phase contains three steps, such as preliminary activities, core activities, and closing activities. The introductory activity aims to orient learning that takes place with the "Pelajar Pancasila" approach and focuses students on carrying out learning activities using learning models. This core activity uses discovery learning (DL) and project-based learning (PjBL) models. DL is a learning model in which students discover and understand new concepts independently through exploration and discovery, with the guidance of teachers who provide questions or problems that trigger students to seek answers independently (Kirschner et al., 2006) (Mayer, 2004). PjBL is a model in which students learn by creating products or projects related to the subject matter. Students can choose the topic to work on and must find creative and innovative solutions to complete the project. This model is considered effective because it can help students develop skills such as critical thinking and problem-solving (Blumenfeld et al., 1991) (Thomas et al., 2015). The closing activity contained student enrichment activities. The initial design form of basic learning design, turning techniques, learning models, DL, and PjBL, as in Figure 2.

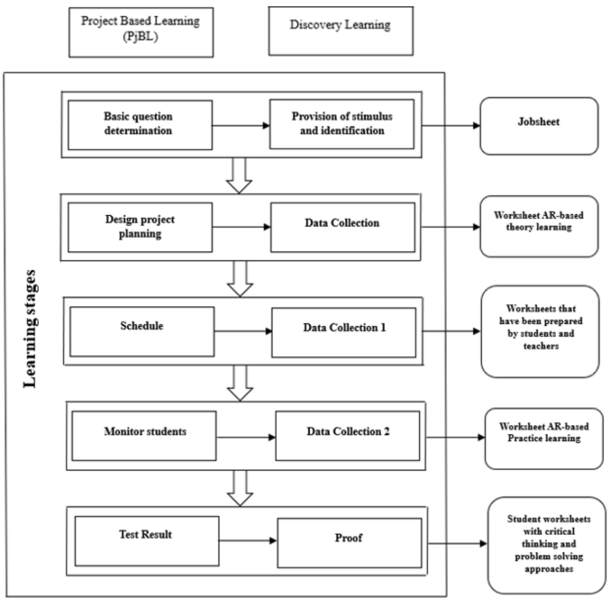

Fig 2: Learning Stage

Learning Activity

Table 5 explains learning activities based on learning syntax DL and PjBL model. Students and teachers must carry out this phase during learning activities.

Table 5. Learning Activities

Learning Syntax (PjBL)	Learning Syntax (DL)	Teacher Activities	Student Activities	Critical Thinking	Problem Solving
Fundamental Question Determination	Stimulus administration and problem identification	The teacher asks students to stimulate through the display of jobsheets and basic questions and stimulate students in AR media	Students are asked to answer the basic questions given by the teacher appropriately together	Focus question, Analyze arguments, Observe and consider observation, Make and determine the results of the consideration, Interact with others	Know and formulate problems clearly, Imagine and live the scope, Ability to analyze and discuss data
Design project planning	Data collection	Teachers provide AR media for students to learn theory independently and individual assignments for students to work on	Students are asked to analyze the video or animation displayed AR and students complete individual assignments given by the teacher	Focusing questions, Observing and considering observations, Making and determining the results of considerations, Identifying assumptions, Deciding on a course of action	Know and formulate problems clearly, Use knowledge to detail analyzing problems from various angles, Imagine and live the scope of cause and effect and alternative solutions, Ability to find and compile data, Ability to make alternative solutions, Ability to calculate consequences
Draw up a schedule	Data processing 1	The teacher asks students to make work steps from the work drawings that have been given and the teacher guides to make a schedule with the students	Students are asked to compile a schedule of work steps that have been made based on the division of the type of turning process for each meeting	Focusing questions, analyzing arguments, Considering the credibility (criteria) of a source, Observing and considering observations, Making deductions and considering the results of deductions, Making and determining the results of considerations, Interacting with others	Know and formulate problems clearly, Use knowledge to detail analyze problems from various angles, Imagine and live the scope, cause and effect and alternative solutions, Ability to analyze and discuss data
Monitor students	Data processing 2	The teacher as a mentor monitors student activities during completing projects and the teacher prepares AR media for students to practice provided by the teacher	Students practice turning according to the steps that have been made using AR media that has been provided by the teacher	Focusing questions, Asking and answering challenging questions, Observing and considering observations, Making and determining the results of consideration, Defining terms	Know and formulate problems clearly, Use knowledge to detail analyzing problems from various angles, Imagine and live the scope, cause and effect and alternative solutions, Ability to find and compile data to present data, Ability to analyze and discuss data, Ability to connect and calculate, Ability to make alternative solutions, Ability to calculate the consequences that occur in each choice
Evaluate	Drawing conclusions	Teachers provide practice questions to test students in critical thinking and problem-solving skills and teachers provide feedback from practical learning	Students are asked to do student test questions in critical thinking and problem-solving skills and students convey obstacles when practicing using machines	Focusing questions, Observing and considering observations, Making inductions and considering induction results, Identifying assumptions, Deciding on a course of action	Know and formulate problems clearly, Use knowledge to detail analyzing problems from various angles, Imagine and live the scope, cause and effect and alternative solutions, Ability to find and compile data to present data, Ability to analyze and discuss data, Ability to connect and calculate, Ability to make alternative solutions, Ability to calculate the consequences that occur in each choice

Development of AR Media

AR media is the development that adapts to technological developments in various fields, including education. The type of AR in this study is projection-based AR (Hololens). Based on the findings regarding the devices used, it was mentioned: 1) mobile phones (43%), 2) tablets (33%), 3) webcams (14%), 4) intelligent lenses or HoloLens (10%) and 5) Helmets or head-mounted displays (14%), MH is still few and has novelty in use as AR devices. MH2 prices are listed on the following website link: https://www.microsoft.com/en-us/hololens/buy. The advantages of using MH2 are based on: 1) Technical Specifications: HoloLens 2 has more advanced technical specifications compared to the first-generation HoloLens, including higher screen resolution, wider field of view, more advanced processor, and better camera. 2) Hand Movement Tracking Capability: HoloLens 2 can accurately track the user's hand movements so that users can interact with holograms using hand gestures without needing additional controllers. 3) Headset Customizability: HoloLens 2 is designed to be more comfortable to use, with the ability to customize the headset to fit the user's head size and face shape. 4) Iris ID for Authentication: HoloLens 2 can read the user's iris ID, so the user can unlock the device and access content quickly and easily without the need to enter a password. HoloLens 2 offers many improvements and new features, making it more advanced and convenient than the first-generation HoloLens. The first stage of HoloLens-based AR development is: 1) preparation; developers install Unity 3D, Visual Studio, and Holotoolkit in this stage. 2) Creating objects: This stage is object creation in unity; these objects can be images, text, 3D or 2D models, and other virtual objects. 3) Add interaction: This stage adds aspects of gesture recognition and voice command; interaction can be done through gesture, voice, or touch. Microsoft Hololens will use motion sensors to map user movements. Create C# code to control the behavior of 3D objects, such as when and how they appear, move, or react to users. 4) Testing: this stage tests and debugs the application on a Hololens emulator or physical Hololens device. Microsoft Hololens is already used in research. Making hololens-based AR uses Unity 3D applications to develop 3D or 2D-based objects (assets) and create animation or movement by providing programming languages and visual studios. Unity 3D features include Rendering, Asset Tracking, Platforms, Physics, and Asset Store. The hardware used to support the Hololens-based AR type is Microsoft Hololens 2. Table 6 names the specifications for Microsoft Hololens 2 and table 7 is the storyboard of the AR Media.

Table 6. Microsoft Hololens 2 Specifications

Type	Specification
Display	Two holographic MEMS (micro-electromechanical systems) displays, with a resolution of 2048x1080 pixels per eye
Field of view	about 52 degrees horizontal and 40 degrees vertical
Processor	Qualcomm Snapdragon 850 Compute Platform, with second-generation HPU features for holographic processing
Memory	4GB RAM, 64GB storage
Sensor	1 ToF depth sensor, four environment understanding cameras, one 8MP photo / 1080p video camera
Audio	Spatial sound with built-in microphone array and speaker
Connection	Wi-Fi 802.11ac 2x2, Bluetooth 5.0, USB-C
Battery	2-3 hours of active use, standby for up to 2 weeks
Weight	566 gram

Table 7. Storyboard AR media

Display	Description
Frontpage 	This page is the front page of an AR-based lathe, which contains the start screen and start menu named Start Now.
Main menu page 	The main menu page contains options consisting of job sheets, basic theory learning turning techniques, jobsheet work step sheets, essential practical learning of turning techniques, and student worksheets.
Working drawing page 	This page contains a working picture with a lighter question: What machine is used? What tools are used? What turning process is done? Explain the product's manufacturing process. Why does the manufacturing process have to be as described earlier? If there is no lathe, what will happen?
The basic theory of turning technique learning page 	The learning page of the basic theory of problem-based turning techniques consists of facing, turning, champer turning, groove turning, taper turning, and hole turning.
Pages of teaching materials with critical thinking and problem-solving approaches 	This page contains material that has a critical thinking and problem-solving approach.
Turning the process material page 	This page contains material on the turning process. The goal is that students learn with a critical thinking and problem-solving approach.
Work steps page 	This work step page contains an animation of the lathe being run step by step.
Basic turning technique practice learning page 	This page displays the holographic object of the lathe; this lathe can interact with humans through touch during the operation of the lathe.

The following is Figure 3 regarding the AR media display flow stages using the MH2 device. With Hololens, users can experience interactive and engaging AR experiences within their surroundings.

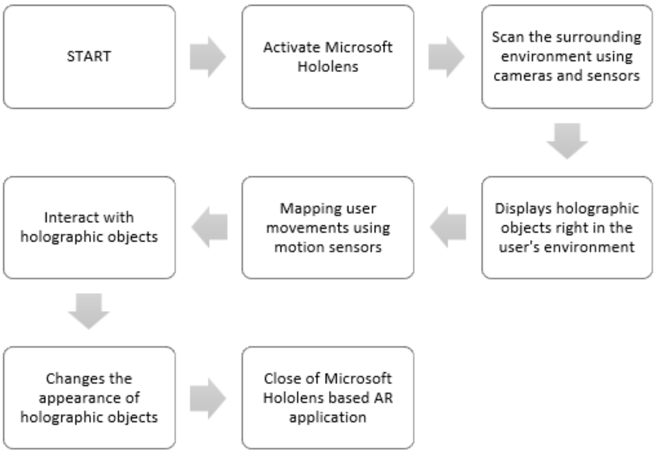

Fig 3: AR Display Flow

Implementation and evaluation in real context

Evaluate Learning Design

The learning design of basic techniques of AR-based turning techniques that can improve critical thinking and problem-solving skills consists of several components that must be validated, namely learning design, storyboards, student activity sheets, critical thinking skills tests, and problem-solving ability tests. The results of expert judgment are based on the assessment format made by the author. Based on the validation results, this learning design is feasible to be applied in mechanical engineering learning at vocational schools with several adjustments based on input from experts. The next step is a field trial to measure the effectiveness of its application in real learning scenarios. Expert judgment is carried out by learning design experts and material experts. After the first validation, the author revises based on what has been discussed by material and learning design experts. The assessment is carried out until the results of the instrument are good. Based on the results of expert judgment assessment, learning design can already be produced into AR media because both from the aspects of preparing learning objectives, competency achievement indicators, determining learning models, Competency Achievement Indicators, learning scenarios (preliminary activities, core activities, and closing activities), jobsheets (Work Drawings and Work Steps), question exercises, evaluation tools, and AR media storyboards. The improvements are based on input from experts. Advice and experts become a reference for improvement that shown on table 8.

Table 8. Suggestions for Development Learning Design

No	Development Aspect	Suggestions and Feedback	Repair
1	Learning objectives	The phrasing of learning objectives must be clear and correct because it will affect other parts.	Arrange learning objectives by the material to be discussed in AR-ba learning.
2	Learning Model	The use of learning models must be based on the learning objectives. The use of learning models can be combined (the use of 2 learning models)	Determining two learning models that can be combined needs to adjusted to the syntax of each learning model.
3	Competency Achievement Indicator	The preparation of the GPA should be based on the lighter questions that have been asked.	Compiling GPA by the steps of the lighter question step for making gl hammer products
4	Learning Scenarios (Introductory Activities)	Preliminary activities have not been fully adapted to the profile of Pancasila students, one of which is critical and creative reasoning.	Steps in the introductory activity are added according to critical a creative reasoning characteristics.
5	Learning Scenarios (Core Activities)	The syntax of learning media used in the scenario is incomplete, and the description of activities needs to have the principles of facilitation, focus, and execution.	Add learning scenarios according to Syntax 2 discovery learning a project-based learning. Revise each activity description clearly students can be facilitated, focused, and executed.
6	Learning Scenarios (Closing Activities)	The closing activity has not been fully adapted to the profile of Pancasila students, one of which is critical and creative reasoning.	The steps in the concluding activity are added according to characteristics of critical and creative reasoning.
7	Jobsheet (Working Drawing)	Working drawings need to be clarified from the drawing information section (add raw material size)	Displays the size of the raw material used in the image informat section
8	Jobsheet	The working step on the turning of the chamber needs to be reversed by the turning of the cartel, the turning of the cartel first because the champer will not be damaged at the time of the cartel turning	The work steps are reversed (cartel turning, then champer turning, a so on)
9	Practice Questions	The preparation of practice questions should be based on learning scenarios of core activities as part of turning facing, turning, chamfering, grooving, drilling, knurling, and taper turning.	Practice questions are made in the process steps of various turr processes using the different turning process materials discussed.
10	Evaluation Tools	Align with Competency Attainment Indicators and create cognitive instruments.	The evaluation tool is adjusted to the Competency Achievem Indicator that has been compiled and makes a cognitive evaluation t instrument.
11	Storyboard	The creation of each storyboard slide is tailored to each scenario created	Storyboards are made based on scenario points with critical thinking a problem-solving approaches; storyboards are made to facilit students in analyzing.

Learning design testing is carried out to determine the feasibility of learning content so that learning objectives are achieved. Learning design uses a combination of learning models: discovery and project-based. Learning activities are made according to the step steps of the interconnected learning model. The screenplay design that has been compiled made a storyboard (AR display) before being applied to AR. So that students, when using AR, are helped to focus on students thinking critically and being able to solve problems.

Design reflection and revision

The results were analyzed to assess the strengths and weaknesses of the AR-based learning design. Strengths of the Learning Design, the integration of AR-based media effectively enhanced students' engagement and motivation. The structured five-phase learning syntax (PjBL and DL) facilitated independent learning and improved critical thinking and problem-solving skills. Teachers found the AR-based approach to be an innovative and interactive method that aligned well with vocational education objectives (Belani & Parnami, 2020). Weaknesses and areas for improvement, some students faced initial challenges in adapting to AR technology, particularly in navigating and utilizing digital tools effectively (Kusuma Zamahsari et al., 2024). Teachers required additional training to optimize the implementation of AR-based learning materials (Marín-Rodriguez et al., 2023). The need for a more flexible learning design was identified to accommodate varying student learning paces and technical proficiency levels. Future AR-based vocational learning designs should integrate adaptive learning pathways to support students with different skill levels (Papakostas et al., 2023). Continuous teacher training should be an essential component of AR integration to maximize instructional effectiveness (Nikou et al., 2022). A feedback loop involving students, teachers, and industry practitioners should be established to refine learning designs and ensure alignment with workforce demands. These insights contribute to the broader development of AR-based vocational education strategies, supporting its scalable application across different technical subjects.

Conclusion

Effective learning design is essential before developing learning media, ensuring that the process aligns with students' needs, particularly in enhancing 21st-century skills. This study successfully developed an AR-based learning design for primary turning techniques, which has been shown to improve critical thinking and problem-solving skills. The proposed design integrates a structured syntax consisting of five phases: 1) determining fundamental questions, 2) designing project planning, 3) preparing schedules, 4) monitoring students, and 5) testing results. Each phase incorporates independent learning activities utilizing AR-based media. Given the positive impact observed, integrating AR-based learning into vocational education curricula beyond this case study is highly recommended. Educators and policymakers should consider embedding AR technology into broader vocational training programs to enhance students' critical thinking and problem-solving abilities, ensuring they meet industry demands. Future research should focus on evaluating the long-term effects of AR on vocational students' workforce readiness. Longitudinal studies and large-scale implementations are necessary to assess how AR influences students' employability, skill retention, and adaptability in real-world industrial settings.

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