

Design and Development of Augmented Reality for the Smart Factory System Course

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Article History:

Received 16 July 2026

Revised 07 Oct 2026

Accepted 12 Oct 2026

Available online 21 October 2026

Kata Kunci : *Augmented Reality, Pembelajaran Daring, Siklus Hidup Pengembangan Piranti Lunak, Sistem Smart Factory.*

Abstract

Integration of technology in the educational paradigm brings a new approach for delivering some courses. Smart Factory System is one of the technical courses that has been elevated and used in online learning. In the old days, this course struggled to achieve its pedagogical outcomes because of a lack of practical and hands-on learning experiences. This study aims to develop an augmented reality (AR) application, specially designed to improve learning experiences by providing an immersive and interactive tool. The waterfall model will be used as the system development life cycle framework. Some phases will be processed in this study, including planning, user requirements, design, development, testing, and deployment. The study resulted in a successful AR application that could produce an interactive 3D model that represents the Xite Automax 520 machine. This concludes that the app has the potential to be used in improving learning experiences for the students of the Smart Factory System class. Some of the limitations had been discovered, such as no empirical efficacy study, only focusing on a single specific machine, and limitations of interactive functionalities in the apps. Future research could elaborate on the quantitative learning impact, expanding to other industrial engineering subjects, and incorporating real-time troubleshooting.

Keywords : *Augmented Reality, Online Learning, Smart Factory System, Software Development Life Cycle.*

Abstrak

Integrasi teknologi dalam paradigma pendidikan membawa pendekatan baru dalam penyampaian beberapa mata kuliah. Sistem *Smart Factory* adalah salah satu mata kuliah teknis yang telah ditingkatkan dan digunakan dalam pembelajaran daring. Pada masa lalu, mata kuliah ini mengalami kesulitan mencapai hasil pedagogisnya karena kurangnya pengalaman belajar praktis dan langsung. Penelitian ini bertujuan mengembangkan aplikasi *augmented reality* (AR), yang dirancang khusus untuk meningkatkan pengalaman belajar dengan menyediakan alat yang imersif dan interaktif. Model *waterfall* akan digunakan sebagai kerangka siklus hidup pengembangan sistem. Beberapa tahap akan diproses dalam studi ini, termasuk perencanaan, kebutuhan pengguna, desain, pengembangan, pengujian, dan penerapan. Hasil dari studi ini adalah aplikasi AR yang berhasil menghasilkan model 3D interaktif yang mewakili mesin Xite Automax 520. Hal ini menunjukkan bahwa aplikasi tersebut berpotensi untuk digunakan dalam meningkatkan pengalaman belajar mahasiswa dalam mata kuliah Sistem *Smart Factory*. Beberapa keterbatasan telah ditemukan, seperti belum adanya studi efektivitas empiris, fokus hanya pada satu mesin tertentu, dan keterbatasan fungsi interaktif dalam aplikasi. Penelitian di masa depan dapat mengelaborasi dampak pembelajaran kuantitatif, memperluas ke mata kuliah rekayasa industri lainnya, dan mengintegrasikan pemecahan masalah secara real-time.

1. Introduction

The rapid advancement and integration of technology into education have spurred the need for innovative approaches to enhance the online learning experience (Wang et al., 2024). Augmented Reality (AR) is a technology that combines digital visuals with the real world, offering the potential to enhance online learning and provide interactive experiences with real-time moving animations (Tasrif et al., 2020; Waskito et al., 2024). With the increasing number of personal smart devices, integrating AR into online education can provide learners with unique and engaging learning experiences (Waskito et al., 2024).

Published research studying AR technology doubled from 2016 to 2020, with much of it focused on university students (Koumpouros, 2024). These studies include exploring the potential of AR to increase student motivation and improve learning outcomes (Khairunnisa & Aziz, 2021; Nurfaidah et al., 2023; Waskito et al., 2024). Mobile-based AR is practical for both face-to-face and distance learning, offering a viable solution for 21st-century education (Waskito et al., 2024). Recent studies have shown that the use of AR in education has a positive impact, both as a new alternative in delivering and presenting lecture materials and as an innovative additional teaching aid to provide students with a near-real experience in certain courses or topics (Kaharuddin et al., 2024; Sumardani et al., 2020; Waskito et al., 2024).

AR has been shown to enhance learners' understanding of complex industry concepts by providing interactive and immersive experiences that encourage integrative thinking (Verner et al., 2022). By adding 3D virtual objects to the real environment, AR enables immersive visualization and hands-on engagement with complex industrial processes, creating a more authentic and practice-oriented learning experience (Bermejo et al., 2023). Previous research also shows that AR improves learner engagement and analytical skills through realistic simulations and visual guidance for distance training in robotics (Grodotski et al., 2023). Such an approach supports practical mastery of workflow and system design, which is critical to meeting the demands of Industry 4.0 (Kaur et al., 2020). However, there are still challenges, such as technical constraints (development/system time) and high costs that hinder the adoption of AR technology (Eswaran et al., 2024; Koumpouros, 2024; Takroui et al., 2022).

The presence of AR technology has reduced dependence on physical facilities, which are often an obstacle in field practice in the field of education (Gavish et al., 2015). It provides a flexible and adaptive learning environment for technical skills training (Kaur et al., 2020). Furthermore, AR technology combined with Digital Twin will enhance the understanding of production system dynamics through 3D visualization of the real world (Gallala et al., 2022). Therefore, AR applications emerge as a strategic tool capable of facilitating virtual field practice for modern industrial engineering education (Grodotski et al., 2023).

The Smart Factory Systems course is a course in the industrial engineering program that focuses on integrating advanced technology into manufacturing processes (Ramírez-Cedillo et al., 2025). This course integrates AR into online learning so that students can gain a more in-depth and interactive learning experience [3]. This integration overcomes the limitations of traditional online learning, which often lacks hands-on practical activities, which are crucial for understanding subjects such as smart factories (Muklis et al., 2022). The presence of AR applications helps bridge this gap by providing interactive simulations and interactions of 3D objects (Waskito et al., 2024).

This study discusses the development of a mobile-based AR application as a learning medium in the Smart Factory System course to overcome the limitations of traditional online learning, as well as improve learners' learning and engagement, which is in line with industry trends and prepares learners to meet the demands of the modern workplace (Takroui et al., 2022; Waskito et al., 2024). The results of this research are in the form of the availability of AR applications integrated into Smart Factory learning.

2. Literature Review

Online learning, or virtual education, is a learning approach that utilizes web-based technology to accommodate the teaching and learning process between facilitators and participants, and allows students to access educational content at any time, regardless of their location or schedule (Azarine & Setiana, 2024; Bossman & Agyei, 2022; Kubikova et al., 2024). They must be connected to the internet

to be able to access the internet and carry out various online activities, such as submitting materials, conducting assessments, and so on (Wang et al., 2024). The definition of online learning itself has evolved over the past few decades, reflecting advances in technology and pedagogical approaches (Azarine & Setiana, 2024; Wang et al., 2024). However, the core elements include digital delivery of materials, flexibility in time and place, and the use of interactive platforms for collaboration and communication (Greenhow et al., 2022). In this study, we define online learning as a form of distance learning in which a course is intentionally designed to be taught entirely online from the outset (Fidalgo et al., 2020).

Online learning offers flexibility in learning, where learners can access materials and take courses from any location and often at a time that suits their schedule (Azarine & Setiana, 2024; Wang et al., 2024). This flexibility is invaluable for anyone looking to further their education without sacrificing other interests (Montenegro Rueda et al., 2024). In addition, online learning also offers the ability to personalize learning for learners (Caroline et al., 2023). With today's technological advancements, online learning has made it possible to offer adaptive materials, self-study modules, and a variety of multimedia resources that suit different learning styles and the needs of learners (Koumpouros, 2024; Wang et al., 2024; Waskito et al., 2024).

However, online learning also faces significant challenges (Azarine & Setiana, 2024; Khairunnisa & Aziz, 2021). These include a lack of social interaction, reduced student engagement and focus, and limited opportunities for practical or kinesthetic learning (Alzahrani, 2020). To address these challenges, the use of AR in online learning has emerged as a promising solution, namely by using 3D models or interactive simulations in the real world (Alzahrani, 2020). This AR technology is able to support hands-on practical learning and make abstract concepts more real and easier to understand (Alzahrani, 2020).

AR is a technology that superimposes visual objects over the physical environment, creating a real-time interactive experience (Alzahrani, 2020; Rojabi et al., 2023). In education, AR technology has been shown to increase learner motivation, supporting kinesthetic learning, attention, and understanding at various levels, making learning more dynamic and effective (AlGerafi et al., 2023; Alzahrani, 2020; Koumpouros, 2024; Saat et al., 2021; Takrouri et al., 2022). In various educational contexts, its applications include online learning, workforce training, and medical education (Saat et al., 2021; Tsai et al., 2014).

Mobile-based AR applications have demonstrated their potential to create engaging virtual online learning (Karacan & Akoğlu, 2021; Rojabi et al., 2023). However, challenges such as cognitive overload, technical issues, and resistance from educators persist (Koumpouros, 2024; Takrouri et al., 2022). Despite these challenges, AR technology is gradually being integrated into education systems worldwide, with ongoing research focused on its effectiveness and future applications (Chen et al., 2017; Rozeena et al., 2019).

In recent research, AR capabilities enhance visualization, interactivity, and real-time feedback, making complex manufacturing concepts more accessible and engaging for learners (AlGerafi et al., 2023; Verner et al., 2022). AR integration, particularly in factory environments, is transforming online learning by making complex industrial concepts more accessible and interactive (Kaharuddin et al., 2024; Takrouri et al., 2022). AR enables learners to visualize and interact with data and machines in real-time, bridging the gap between theoretical knowledge and practical applications in manufacturing and automation (Baroroh et al., 2021; Danandjaya & Wibawa, 2021; Wu, 2025; Yutthanakorn & Charoenseang, 2023).

3. Previous Work of Augmented Reality in Online Learning

The use of AR applications in learning is increasingly seen as an effective pedagogical instrument in increasing engagement, motivation, and learning outcomes at various levels of education (Alzahrani, 2020). As shown by research (Eldokhny & Drwish, 2021), the implementation of AR applications in learning during the COVID-19 pandemic contributed to improving learners' academic achievement and design skills at the university level. Study (Çetin & Türkan, 2022) also reported that the use of AR-based applications in learning contributed to improving learner learning achievement and attitudes.

Learning using AR applications plays a role in guiding students when understanding topics that are complex or unfamiliar to them (Baroroh et al., 2021). These findings indicate that learning using AR applications as a learning medium is very effective in supporting cognitive and affective outcomes in the context of distance education (Khairunnisa & Aziz, 2021; Nurfaidah et al., 2023; Waskito et al., 2024).

In the context of engineering program education, smart factories act as a bridge between the theoretical foundations in the academic environment and their application in industrial practice (Ramírez-Cedillo et al., 2025). Through a smart factory AR application designed to represent real-world production conditions, learners are introduced to key technologies in the Industry 4.0 era, including robotics, simulation, the Internet of Things (IoT), and digital twins (Danandjaya & Wibawa, 2021). This approach strengthens learners' theoretical understanding by directly observing the smart factory production flow process, thus supporting the acceleration of knowledge transfer from industry to the academic environment (Ramírez-Cedillo et al., 2025). In addition, the smart factory AR simulation concept offers a platform that supports research and innovation activities through the implementation of virtual and hybrid scenarios, including virtual commissioning and programmable logic controller (PLC) integration (Bossman & Agyei, 2022). These methods enable learners to develop multidisciplinary problem-solving skills while reducing the risks associated with using physical equipment (Koumpouros, 2024; Ramírez-Cedillo et al., 2025; Takroui et al., 2022). Not only that, but it also supports the industry's need for graduates who are adaptive, able to operate in a human-robot interaction environment, and ready to face the demands of efficient and sustainable production (Fidalgo et al., 2020).

Despite the use of AR to introduce smart factories, no previous studies have been found that developed AR using the Xite Automation 520 model for this purpose. In their study, Tsmots et al. (2019) created two equipment models for the demonstration: the Cable 6-Axis Robot Arm and the EXCT 100 movement system (Tsmots et al., 2019). This research gap motivated our study.

4. Method

This research uses the Software Development Life Cycle (SDLC) approach using the waterfall model because its structured and sequential stages are able to support the systematic planning, implementation, and evaluation processes of the system during development (Sumardani et al., 2020). Research begins with the planning phase, where the overall project scope, resources, and timeframe are determined. Next, the user requirements stage aims to ensure that the application is designed to meet the specific needs and challenges of the learners (Sumardani et al., 2020). This is then continued with the design phase, which includes preparing detailed architectural, 3D asset design and interface designs as well as determining the appropriate AR technology to ensure the usability and effectiveness of the system. After that, the AR application development stage is carried out based on the established design, by utilizing the Unity Engine platform for three-dimensional modeling and AR feature integration.

After application development is complete, it is continued with testing using black box testing methods and user trials to evaluate the functionality, reliability, and user experience of the system. The focus of black box testing is the evaluation of the functionality of an application without examining the internal architecture or source code (Sumardani et al., 2020). This approach provides a comprehensive evaluation of the system's level of compliance with established requirements and its suitability for user needs (Danandjaya & Wibawa, 2021). The feedback obtained from this testing is used to refine the application and ensure that it meets the defined user requirements. After passing the testing stage, the final step is to enter the deployment stage, which includes submitting the application to the App Store and Google Play Store.

5. Results & Discussion

This research successfully developed an AR application that demonstrated consistent performance with development carried out systematically and thoroughly documented using the waterfall methodology.

5.1. Planning Phase

The first phase in the SDLC development method includes determining the project scope, identifying the required resources, and establishing a development schedule for the AR application. The main objective within the scope of this project is to produce an AR application that allows learners to actively interact with the system by observing a simulation of the production process to produce output products.

We use Unity Engine, which is a game engine used to develop AR applications that incorporate 3D representations of Smart Factory components and workflows. In this study, a mobile-based AR application was developed with the aim of facilitating access and interaction with virtual objects via learners' smartphones. This approach is expected to increase learners' engagement, learning independence, and conceptual understanding in the context of the Smart Factory Systems course.

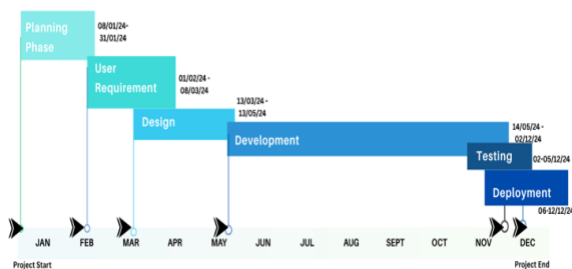


Figure 1. Project Timeline



Figure 2. Xite Automax 520 Machine

The project timeline, which runs from January 8, 2024, to December 6, 2024, consists of six main phases: Planning, User Needs Analysis, Design, Development, Testing, and Implementation, as shown in Figure 1. This timeline reflects a systematic development process and is designed to ensure effective project monitoring and enable continuous evaluation of the implementation and utilization of the AR-based learning system throughout the project life cycle.

For the successful development of AR applications, various human resources, servers, and material resources will be required. Setting up a human resource team consisting of project managers, AR developers, 3D designers, and Smart Factory experts. The task of coordinating activities at all stages of development and ensuring adherence to the planned schedule is assigned to the project manager. For the design and programming of AR applications using the Unity platform, it is handed over to AR developers. To create and visualize 3D Smart Factory components, a 3D designer is assigned. To ensure the accuracy, pedagogical relevance, and technical correctness of the simulated manufacturing process, it was assigned to experts in the field of smart factories.

The server infrastructure for the AR application uses Microsoft Azure cloud services, which offer high availability, scalability, and secure access for learners. For the management and storage of structured data, including student activity records and simulation parameters, SQL Server database management is used. Finally, to optimize the distribution of 3D assets and multimedia content, a Content Delivery Network (CDN) service is used, with the aim of ensuring the application is accessible across various geographic locations, especially for learners who have low-latency access, and to ensure stable application performance.

For smart factory AR development, reference materials and visual assets are required. Therefore, a miniature model of the Xite Automax 520 Machine is used as a reference to create a 3D model of the machine, which will serve as an asset used in this project. The Smart Factory Machine is a miniature version of the Industry 4.0 system that can provide students with an overview of Industry 4.0 technology. This machine consists of three individual stations that showcase product assembly, from raw material retrieval to storage in the warehouse. The original miniature model of the Smart Factory is shown in Figure 2.

5. 2. User Requirement Phase

This stage is an important stage in the development of AR Smart Factory, which focuses on identifying user needs, determining important system features, and designing learning interactions that align with the learning objectives of the Smart Factory System course. Based on the developed

Storyboard, this phase simulates the learning journey and sequence of interactions experienced by students in the AR Smart Factory application.

The learner begins by opening the AR Smart Factory application. After accessing AR Smart Factory, the main display is a 3D model of the Xite Automax 520 machine as the main interface. In this 3D visualization, several interactive instructions are shown, each corresponding to a specific station on the machine. These instructions serve as interactive bookmarks that, when selected, provide detailed mechanical explanations of the components. There are three pointers representing three different stations on the machine, namely the rack station, the processing station with pneumatic/hydraulic presses, and the high rack storage station. To mark the selected area, the related component will change color when the pointer is clicked. Not only that, but component name information and descriptive information are also displayed. Learners can also rotate their 3D models, allowing them to dynamically explore the structure from multiple viewpoints. Table 1 shows a complete list of components for each station.

Table 1. Component For Each Station

	Station 1	Station 2	Station 3
Component	• Separating racks • Conveyor belt • Sensors • Profibus Coupler (behind conveyor belt) • Picking unit	• Pinning Unit • Conveyor Belt • Sensors • Portal • Press	• Cartesian Robot • Conveyor Belt • Sensors • High Rack Storages

The machine production workflow is the main feature that can be displayed by pressing the demo button. In this mode, learners will be presented with the automated workflow of a smart factory by observing how machines operate sequentially. In addition, instructional information is also provided to guide students through the simulation process.

Production simulation begins by entering the desired product combination and production quantity before selecting the Release Order command to start the manufacturing process. In the Material Description menu, there are four product color combinations available, namely: white–white, white–black, black–black, and black–white. The first color indicates the raw material block located at the bottom. After Order Approval Confirmation, the system will automatically execute the production sequence, allowing learners to observe and understand the complete workflow of the Smart Factory environment dynamically and interactively. This production flow can be seen in Figure 3, and a detailed description of the production workflow is in Table 2.

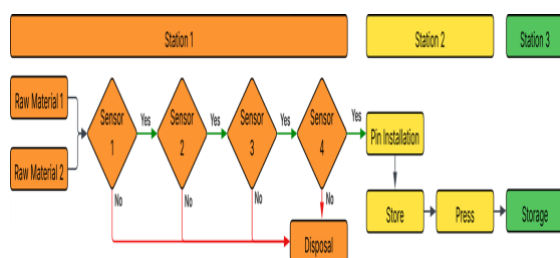


Figure 3. Production Workflow Diagram

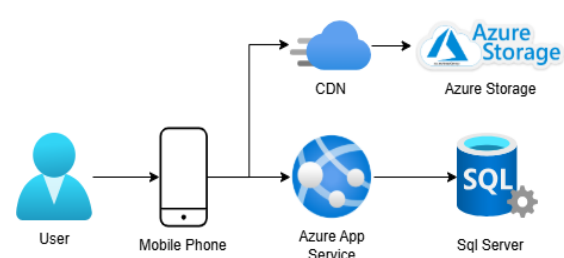


Figure 4. System Architecture Design

After the 13th process, the production process returns to process 1. During the inspection or QC process, both materials (1 and 2) undergo the following inspection procedures:

1. Capacitive sensors are components that function to check the presence of material (sensor 1)
2. Pneumatic cylinders are components that function to check the dimensions/depth of materials (sensor 2)
3. Inductive is a type of inductive or non-inductive material (Sensor 3)
4. Optical sensors are color detection components (sensor 4)

Capacitive sensors function to detect the presence of material by measuring changes in capacitance caused by the proximity of an object. With this sensor, the material is verified to be correctly placed before production begins, to prevent misplacement that could affect the quality of the final product.

Table 2. Detailed Description of Production Workflow

No	Material 1	Material 2
1	Raw material comes out of the separating racks and is carried by the conveyor in the open state	Idle on separating racks
2	Raw material enters the checking/QC process using 4 sensors	Idle on separating racks
3	After checking, if there are errors in the position, color, and material, the raw material will be transferred to the picking unit. If everything is suitable, continue to station 2	Idle on separating racks
4	After entering station 2, the raw material will be pushed to the pinning unit, to be pinned.	Raw material comes out of the separating racks and is carried by the conveyor in a closed position
5	The process of installing the pins on raw material 1 and returning it to the conveyor	Raw material enters the checking/QC process using 4 sensors
6	Raw material to press unit	Waiting for raw material 1 to reach the press unit
7	The raw material is brought to the press unit by the portal unit of the conveyor	Waiting for raw material 1 to reach the press unit
8	Raw material 1 waiting raw material 2	Raw material to press unit
9	Raw material 1 waiting raw material 2	The raw material is brought to the press unit by the portal unit of the conveyor
10	The process of combining raw materials 1 and 2 on the press unit. After combining raw materials 1 and 2 into a product	
11	The product is transferred to the conveyor by the unit portal	
12	Products journey to station 3	
13	At station 3 the products are arranged into high rack storages by cartesian robots	

Pneumatic cylinder sensors are sensors that function to inspect the dimensions and depth of materials with the aim of verifying that each material component is positioned accurately in the production line. Especially for Material 1, which has an open structure with a hole in the middle, in contrast to Material 2, which has a closed or flat top surface. This mechanism ensures that the material is placed in the correct position; any deviation or misalignment detected will trigger the material to be automatically moved to the picking unit for correction or disposal.

An inductive sensor is a sensor that can differentiate material composition and determine whether a component is made of metal or plastic. Certain components are manufactured from metal in the original engine. In this study, the material is assumed to be plastic and is limited to only 2 color variations, namely white and black, which aims to simplify the visual representation while maintaining functional consistency for learning and demonstration.

The color detection component uses an optical sensor that functions to detect the color of the material before proceeding to the next production stage. They are operated by synchronizing the combination of products that have been selected by the learner. For example, if a student chooses a material with a black-white color combination, the system will select material 1 with black color and material 2 with white color. Therefore, when the optical sensor detects white material on the top surface, the system will classify it as defective material even though its position is correct. The aim of this process is to ensure that product quality and consistency are maintained before proceeding to the next stage in the production process.

To simulate the production flow, the system needs to know the processing time for each step. Therefore, systematic observations and experiments were conducted on the Xite Automate Machine. Based on systematic observations and experimental trials conducted using the Xite Automate machine, a detailed process-time table was developed to represent the logical flow embedded within the system's programming. Table 3 captures the cycle time required for each operational stage experienced by both Raw Material 1 and Raw Material 2 throughout the automated production workflow.

5.3. Design Phase

In this design phase, there are four (4) highlighted components: system architecture, flowchart, activity diagram, and user interface. The design of the system architecture will provide the mobile

application with its cloud-based service architecture (Figure 4). By default, learners will use their mobile phones to access the application. Interfaces of the application developed in Azure Application Service, which will host both the APIs and the web application. This Azure Application Service will be in charge of creating seamless communication between every system layer. Meanwhile, the SQL Server will manage the data traffic in the database to serve requested data by learners and systems while maintaining the integrity and consistency of the data. Furthermore, Azure Storage will provide the distribution of static files (images, videos, and documents) to the application. The proposed system architecture provides high scalability, security, and performance of the application, enabling it to handle load access while delivering optimal experiences for the learners. The Xite Automation 520 physical machine was used as a model to design a 3D model of the Xite Automation 520.

Table 3. Time Production Process

Raw Material 1		Raw Material 2	
Description	Cycle Time	Description	Cycle Time
Transfer of raw material to conveyor	1'	Separating Racks (idle)	11'
Sensor inspection	5'		
Transfer to station 2	5'		
Pin installation at the pinning unit	9'	Transfer of raw material to conveyor	1'
		Sensor inspection	5'
Transport to portal unit	4'	Waiting at Conveyor Station 1	10'
Transfer from conveyor to press unit	5'		
Waiting for Part 2 at the press unit	10'	Transport to portal unit	7'
		Transfer from conveyor to press unit	5'
Press process (integration of Raw Materials 1 and 2)	7'	Press process (integration of Raw Materials 1 and 2)	7'
Transfer to Station 3	10'	Product transfer to Station 3	10'
Product placement into storage by Cartesian robot	10'	Product placement into storage by Cartesian robot	10'
Total Cycle Time	66'	Total Cycle Time	66'

When the learner launches the application for the first time, it will display some transitions to direct the learner to the main interface. The transitions will continue to put the application in AR mode. In this mode, the learner shall be able to interact with the 3D model along with their physical environment through the mobile phone's (or another gadget's) camera. At this stage, learners are instructed to scan the floor surface to identify predefined markers or spatial areas required for AR object placement. Once the scanning process is successful, the application renders a three-dimensional Smart Factory model along with informational panels corresponding to each component within the system—Figure 5 shows the flowchart of the system.

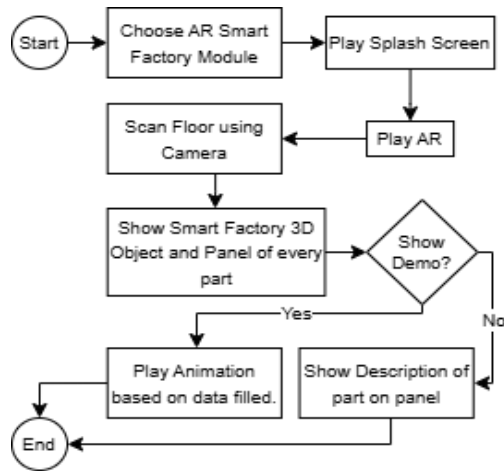


Figure 5. Flowchart Of The System

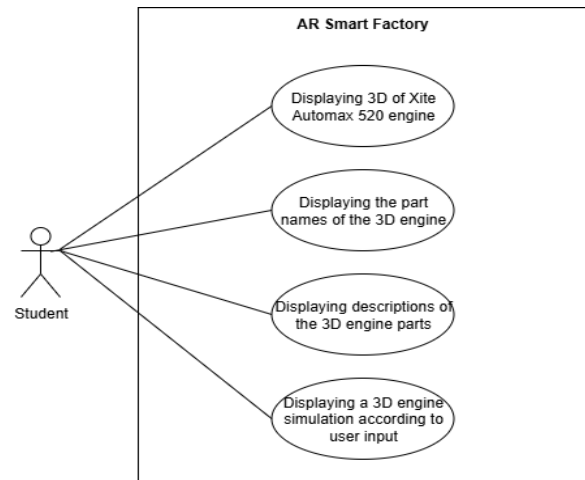


Figure 6. Activity Diagram

The use case diagram in Figure 6 shows the relationship between the learner and the functionalities of the system. Functionalities of the AR Smart Factory are to display the engine, part, description, and simulation of Xite Automax 520. Generally, learners would be directed to see the engine first, before they could further look at the part and description. In the end, the learner could see the simulation based on scenario input. At the beginning of the system, the screen will present an initial interface, acting as the home. In this screen, the learner could do floor or any flat surface scanning to detect and start rendering the 3D objects. The system will display the engine after completing the scanning process. It will also display information and description panels for every component. The learner could choose to do some actions in this display. The learner could initiate the simulation based on given configuration data or view a detailed description of each component they would like to foresee.

The user interface (UI) of the system was designed to accommodate intuitive interaction from the learner. UI provides a concise information flow, so the navigation would be seamless in an augmented reality environment. Figure 7 shows the 3D model's initial screen, which shows the 3D model in the center. This model will serve as the primary object. The model is surrounded by some interaction control buttons. Some of the controls include Back, Help, Scale, and the Demo button. The back button will be used by learners when they want to return to the previous page. The help button will be used to show brief guidance for using the features. The scale button will allow learners to make the same changes in the size of the model. The demo button provides a simulation of the workflow of Smart Factory

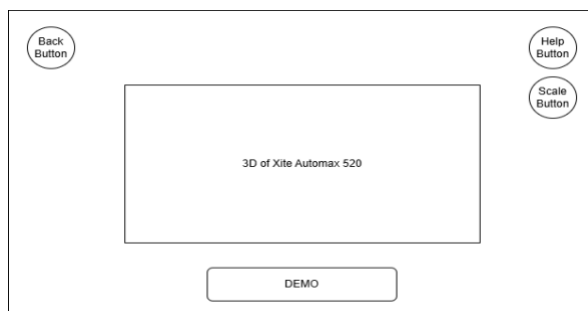


Figure 7. Initial Interface Display

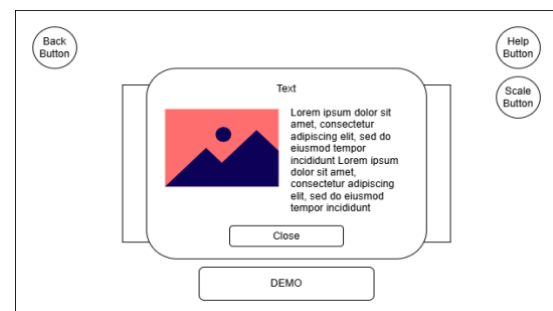


Figure 8. Popup Part Description Window

When the learner moves into the part description window, they may select a specific part to see its detailed information. The information will appear in a pop-up panel. This panel provides a visual preview of the part and a detailed description of it. The panel also accommodates a close button, so the learner can return to the previous window. This panel was designed following a card-based layout. This layout is a common approach to improve readability and provide special consistency for the learner's view.

If the Button Demo is clicked, Figure 9 will appear. The learner will be asked to input the material description and quantity field. The learner may click the Order Release Button to confirm the input. The Cancel Button means the order is not executed, and the Order Release Button indicates the order has been processed for production.

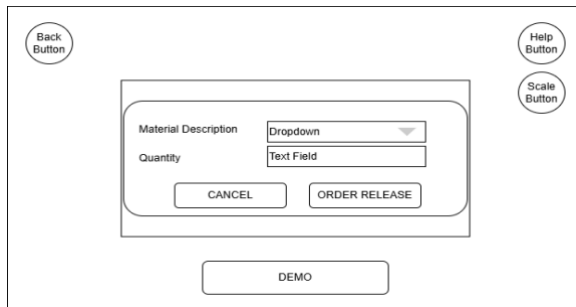


Figure 9. Data Simulation Screen

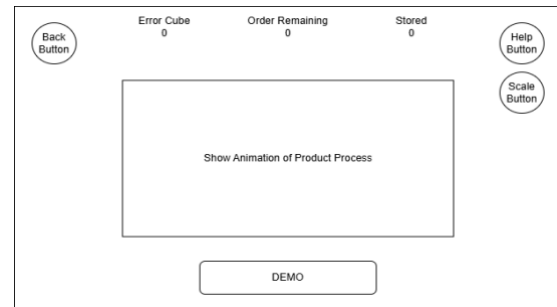


Figure 10. The Screen Showing The Simulation Process

After clicking the order release, continue to the screen showing the simulation production process, as shown in Figure 10. The upper screen display shows indicators such as error cube number, order remaining, and stored, which provide real-time production information. After the production simulation finishes, display a pop-up message saying “Your Order is completed.” There is an OK button to close the notification and return to the initial interface display. Meanwhile, the indicator status still appears at the top of the display to maintain information consistency. The design screen of the completed process information is shown in Figure 11.

5.4 Development Phase

The AR application was developed using Unity. Used version is 2022.3.52fl. Unity accommodates creating an interactive application across various environments, 2D, 3D, VR, and AR. It supports the AR integration through various software development kits and their extensive. It also supports cross-platform development in a mature ecosystem. It has a beneficial capability for scalability and compatibility across devices. Blender V6 is used for 3D model development. It's open source and a standard tool. Blender is also very reliable for animation and workflow rendering. The result of 3D assets could be used in Unity.

C# is used in this project. C# is the native scripting language for Unity. C# is used to implement the logic of the application, manage interaction controls of AR, and integrate the 3D object with the user interface components. The collaboration between Unity, Blender, and C# could deliver a flexible and efficient asset creation, besides, they could provide interactive features and integrate seamless AR. A combination of these technologies could develop an interactive AR that could boost learner engagement and students' understanding by providing an immersive visualization. This project started on March 13 and ended on May 13, 2024. The result of the system's development could be seen in Figures 12 to 26; meanwhile, the development results of the UI design are shown in Figures 7 to 11.

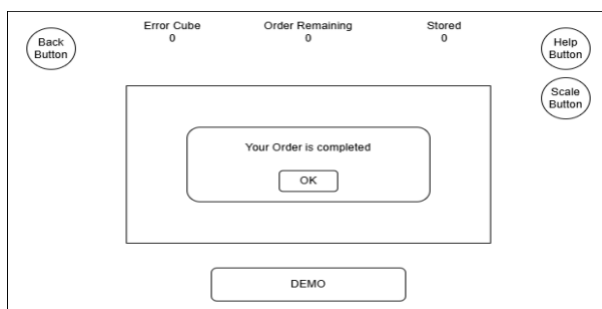


Figure 11. The Screen Displays The Completed Process Information



Figure 12. Display Device Showing The Names Of 3 Stations



Figure 13. Showing The Part Description

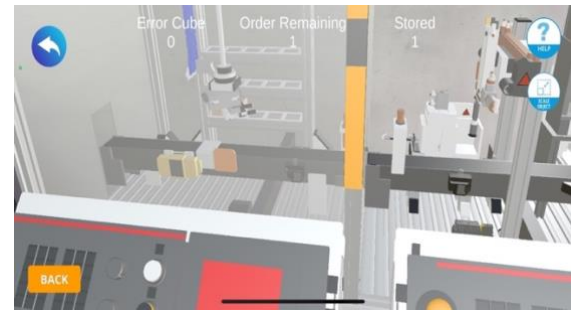


Figure 15. The Displaying Device Underwent Simulation

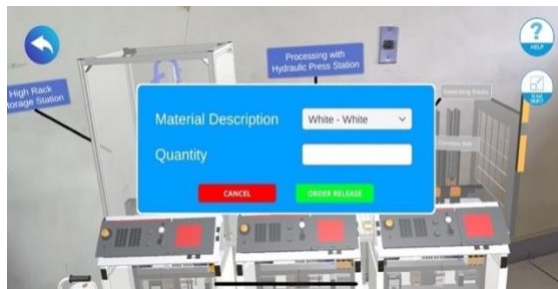


Figure 14. Displaying Learner-filled Data Used For Device Simulation

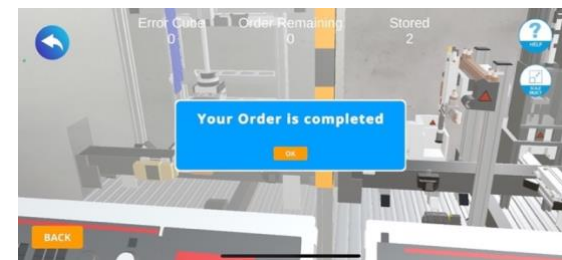


Figure 16. Displaying The Pop-up Menu After The Simulation

5. 5. Testing Phase

During the testing phase, we conducted black-box testing from December 2, 2024, to December 5, 2024. Bug fixing and re-testing were performed as scheduled. The results of black-box testing are shown in Table 4.

Table 4. Black-box Testing Results

No	Functional	Explanation	Test Result
1	Main interface display	Once the AR application is opened, an initial pop-up interface displays the 3D machine along with back, help, scale, and demo buttons.	Passed
2	Back Button Functional	Clicking the back button will close the application.	Passed
3	Help Button Functional	The Help button will display a pop-up window with helpful information or support.	Passed
4	Scale Button Functional	The scale button enables learners to change both the size and position of the 3D machine model.	Passed
5	Open Separating Racks Description	Clicking the separating racks panel will trigger a pop-up that displays the description of the separating racks.	Passed
6	Open Conveyor Belt Description	Clicking the conveyor belt panel will trigger a pop-up that displays the conveyor belt's description.	Passed
7	Open Sensors Description	The sensors panel will display a pop-up window with the sensor descriptions.	Passed
8	Open Profibus Coupler Description	Clicking on the Profibus coupler panel will trigger a pop-up that displays the description of the Profibus coupler.	Passed
9	Open Picking Unit Description	Clicking the picking unit panel will trigger a pop-up that displays the picking unit's description.	Passed
10	Open Pinning Unit Description	Clicking the pinning unit panel will trigger a pop-up that displays the pinning unit's description.	Passed
11	Open Conveyor Belt Description	Clicking the conveyor belt panel will trigger a pop-up that displays the conveyor belt's description.	Passed
12	Open Sensors Description	Clicking the sensors panel will trigger a pop-up that displays a description of the sensors.	Passed
13	Open Portal Description	Clicking the portal panel will trigger a popup that displays the portal's description.	Passed
14	Open Press Description	Clicking the press panel will trigger a pop-up that displays the press description.	Passed

No	Functional	Explanation	Test Result
15	Open Cartesian Robot Description	Clicking on the Cartesian robot panel will trigger a pop-up that displays the Cartesian robot's description.	Passed
16	Open Conveyor Belt Description	Clicking the conveyor belt panel will open a pop-up showing the conveyor belt's description.	Passed
17	Open Sensors Description	Clicking the sensors panel will trigger a pop-up that displays the descriptions of the sensors.	Passed
18	Open High Rack Storages Description	Clicking the high rack storage panel will trigger a pop-up that displays the description of the high rack storage.	Passed
19	Demo Button Functional	Clicking the Demo button will open a pop-up where you can enter simulation data.	Passed
20	Simulation Functional	The learners fill out the simulation data pop-up and then click the 'Release Order' button.	Passed
21	"Back" Button Functional	Clicking the Back button will exit simulation mode.	Passed
22	The simulation process is finished	Once all materials in the rack are depleted, the system will display an 'Order Completed' pop-up. The learners should then click OK to return to the initial stage of the simulation cycle.	Passed

5. 6. Deployment Phase

The AR application is deployed for Android and iOS platforms. Android packages have been submitted to Google Play, whereas the iOS packages are to the App Store. The iOS app can be accessed on App Store, at <https://apps.apple.com/id/app/ar-binus-online/id6450821487>, meanwhile, the Android one can be accessed on Google Play, through the link of <https://play.google.com/store/apps/details?id=id.ac.arbinusonline&hl=id&gl=US>.

6. Conclusion & Future Works

This study used a waterfall SDLC. This study carefully planned, designed, developed, tested, and implemented the AR application for the Smart Factory System Course. The AR application was built using the Unity engine, 3D modeling in Blender, and scripting in C#. This application successfully implemented augmented reality technology to increase students' learning experiences.

The AR application was developed for Android and iOS platforms. The application provides a potentially improved learning experience for students by offering a close-real-life visualization of complex industrial processes. Students could also interact with virtual models produced by the Xite Automax 520 machine. This 3D model provides a better simulation of the process flow of line production and how the manufacturing equipment could support the production process. This approach could help students to have a better understanding of the course. The implementation of this AR application has the potential to improve the learning experience for students in the Smart Factory Course Class.

This AR application shows some potential for wider use in education. For future research, an empirical study could be established to evaluate the usage of AR applications quantitatively on their impact on the final score for completing this course. The simulation of this AR application could also be expanded to add other production lines with broader production scenarios. This expansion will involve a broader framework, since it will simulate more complex scenarios. Some innovation could also be created by allowing the app to handle multiple students, so they could interact in the same virtual environment simultaneously. All these improvement plans could boost students' learning experiences. Future research should also be aware of cost-effectiveness, long-term usability, scalability, and consider reducing the technical delay. This AR application also has the potential to be used in more adaptive learning paths, which will provide personalized experiences.

7. Research Implication & Limitation

The results of this study have practical implications: we contribute a 3D model of the Xite Automation 520 asset, which we had not found previously, and integrate it into the Smart Factory Systems course for industrial engineering students to overcome conventional education and carry out production line simulation practices in a virtual environment in the manufacturing industry. We also

consider the possibility of implications for students' learning in online learning through the use of virtual industrial equipment like the Xite Automax 520.

We recognize that there are several limitations to this study that need to be considered. The first limitation in this research is the lack of empirical evidence that quantitatively measures the direct impact of AR tools on student learning outcomes, knowledge retention, and skill development compared to traditional teaching methods. Next, the application scope is quite limited since it's only simulating a single machine, although it could be applied to broader environment of industrial systems, or other lines of production. There is also limitation in its functionality, that is deficient for advanced interaction. Some of enhancements that could be applied in the future such as integration of physical sensors with real-time data, exercises for simulation of troubleshooting, and environment that supports multi-user collaboration. Finally, the present study did not comprehensively investigate the sustained usability, scalability, or approaches to optimizing the cost-effectiveness of the AR solution development across diverse educational contexts.

Acknowledgment

The author acknowledges the BINUS University internship students who contributed to developing the 3D Virtual Model of the Xite Automax 520 Machine during their internship from February 2024 to February 2025. The author also declares the use of the following generative AI tools in the preparation of this manuscript: Consensus.app, Notebooklm.google.com, app.Jenni.ai, and Grammarly. Consensus.app is used to find articles that will be referenced in this paper. Notebooklm is used for text extraction and to identify themes based on research needs. App.Jenni.ai is used for drafting, improving sentence fluency, and enhancing phrasing in academic writing. Grammarly is used to enhance the overall quality of the manuscript.

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