A Markerless Augmented Reality Learning Aid for Microelectronic Fabrication

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DOI: https://doi.org/10.47772/IJRISS.2026.101000746

Received: 27 October 2026; Accepted: 02 November 2026; Published: 17 November 2026

ABSTRACT

Microelectronics fabrication requires learners to connect successive processing operations with changes in semiconductor structures. Conventional learning materials can make these spatial and sequential relationships difficult to visualise. This study presents the development and preliminary user evaluation of a markerless augmented reality (AR) mobile application for learning selected microelectronics fabrication processes. Three-dimensional models were created in TinkerCAD and integrated into Unity, with C# scripts supporting scene navigation and model manipulation. The Android application combines fabrication models with explanatory text, rotation controls, and scaling functions. A descriptive questionnaire involving 18 engineering students examined perceived information delivery, usability, engagement, and understanding. All respondents agreed or slightly agreed that the application provided additional fabrication information, while 88.9% responded favourably to both ease of use and clarity of information delivery. Furthermore, 94.4% considered the application interactive and enjoyable, and 83.3% reported increased interest in fabrication processes. The proportion selecting ratings of 3–5 for self-assessed understanding increased from 77.8% before use to 100% after use. These findings suggest favourable initial user acceptance and perceived instructional value. However, the small sample, reliance on self-reported responses, and absence of an objective knowledge assessment limit conclusions about learning effectiveness. The prototype provides a foundation for further content refinement, technical testing, and controlled evaluation of AR-supported microelectronics learning.

Keywords: Augmented Reality, Microelectronics Fabrication, Markerless AR, Engineering Education, Interactive Visualisation.

INTRODUCTION

Microelectronics fabrication provides the technological foundation for modern electronic systems, supporting applications ranging from consumer devices to advanced computing (Singh et al., 2024). Semiconductor devices are produced through interconnected operations, including thin-film deposition, photolithography, etching and doping. These operations add materials, define patterns, selectively remove layers and modify semiconductor properties. Understanding how these processes work together is therefore an important component of semiconductor technology and electronic engineering education.

A central objective of microelectronics education is to help students explain how a semiconductor substrate is progressively transformed into a functional device. This requires both conceptual and procedural understanding. Conceptual understanding concerns the purpose and underlying principles of an operation,

whereas procedural understanding concerns how operations are performed and organised within a fabrication sequence (Silver, 2013). Students must connect what changes during a process, where the change occurs and why it is necessary for subsequent stages. For example, understanding photolithography and etching requires students to distinguish between the temporary photoresist pattern and the underlying material to which the pattern is transferred.

Teaching these relationships can be challenging because many relevant structures and material transformations occur at scales that cannot be observed directly without specialized equipment. Diagrams and videos provide valuable explanations, but students must still interpret spatial relationships and mentally connect the intermediate stages of device formation. Practical exposure can also be constrained by equipment costs, laboratory availability and safety requirements. These conditions create a need for supplementary learning resources that connect fabrication explanations with accessible representations of structural changes.

Augmented reality (AR) offers one approach by integrating digital content with the student's physical environment (Antonioli et al., 2014; Tekedere & Göke, 2016; Yildiz, 2022). Through a compatible mobile device, an AR application can display three-dimensional models alongside process descriptions and allow users to adjust their viewing orientation and size. For microfabrication learning, these features offer a way to associate individual operations with the structures they produce. Previous studies have explored AR in technical and science education. Ismail et al. (2018) examined an AR teaching kit in technical education, Noh et al. (2010) investigated AR-content-based instruction in relation to learning interest and achievement, and Turan and Atila (2021) explored AR-supported science learning among students with specific learning difficulties. These studies motivate further investigation, although their findings cannot be assumed to apply directly to microelectronics fabrication.

Advances in hardware, computer vision and mobile computing have supported the development of AR technology in recent years, as illustrated in Fig. 1. AR applications generally employ marker-based or markerless tracking. Marker-based systems use recognisable visual targets to position digital content, whereas markerless systems can use environmental features and device sensor data. Gao et al. (2017) investigated techniques related to AR registration and tracking. For mobile learning, markerless tracking removes the need for a dedicated printed target, offering greater flexibility in where the application can be used. Its educational suitability, however, also depends on aligning the models, explanations, and interaction controls with the intended learning objectives.



Fig 1. The Development of AR Technology in Recent Years.

For microfabrication education, the instructional opportunity lies in connecting process order, material changes and structural outcomes. A dedicated application can present selected fabrication stages as a coherent sequence and provide opportunities to inspect their associated structures. Such a resource is intended to complement lectures, textbooks and practical activities. An initial user evaluation can help determine whether students find the application accessible, its explanations clear and its representations useful, while identifying aspects requiring further refinement.

Accordingly, this study presents the development and initial user evaluation of a markerless AR mobile application for learning selected microelectronics fabrication processes. The objectives are to develop three-dimensional models representing selected fabrication stages, integrate process descriptions with interactive model manipulation and sequential navigation and examine students' perceptions of usability, information delivery, engagement and support for understanding. The study contributes a fabrication-specific learning prototype and descriptive questionnaire findings that inform its further development.

METHODOLOGY

1. Study Design

The study combined application prototyping with a descriptive questionnaire-based user evaluation. Development comprised three-dimensional model preparation, AR scene construction, interface scripting, Android deployment and functional checking. Following development, questionnaire responses were collected from engineering students to examine their experiences with the application. The evaluation focused on perceived usability, clarity of information, engagement and self-assessed understanding. It did not include an objective fabrication-concept test or a comparison group. The findings were therefore analysed as initial user feedback rather than as a measure of instructional effectiveness.

2. Development tools and model preparation

TinkerCAD was used to create simplified three-dimensional fabrication models. Unity provided the environment for integrating the models, arranging application scenes and assembling the interface. C# scripts were developed using Microsoft Visual Studio to control navigation and model manipulation. The completed application was exported as an Android application package (APK). Table 1 display the software used to develop the AR application.

Table 1. Software Tools and Their Functions.

Tool / Platform	Function
TinkerCAD	Creation of simplified fabrication models and export in OBJ format.
Unity	Integration of models, AR scenes, process descriptions, and interface elements.
Microsoft Visual Studio	Development of C# scripts for navigation and model manipulation.
Android	Installation and operation of the completed mobile application.

The model set represented selected fabrication stages, including deposition, photolithography, etching and resist removal, together with associated photoresist and etch-mask structures. Individual assets were exported from TinkerCAD as OBJ files and imported into Unity. The models were arranged in an instructional sequence to associate fabrication operations with changes in the represented structure as shown in Fig. 2. They were designed as visual learning aids rather than physically calibrated simulations. Consequently, their geometry

illustrated selected material and structural relationships without reproducing process kinetics or manufacturing dimensions.

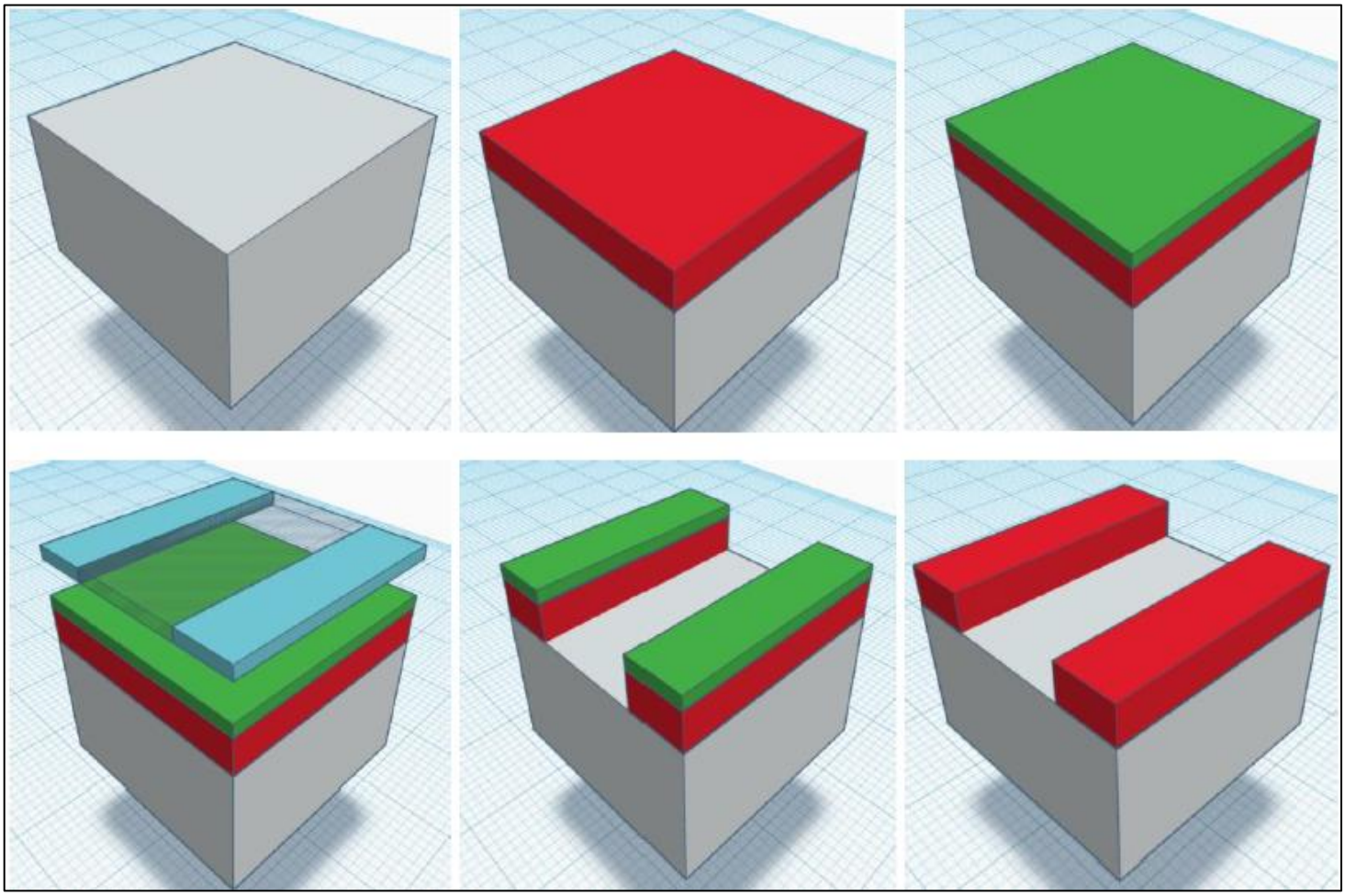


Fig. 2 Three-Dimensional Fabrication Models Created in Tinkercad.

3. AR Integration and Interaction Design

The application used a markerless AR approach without a dedicated printed image target (Pooja et al., 2020). Its workflow began with a main menu, followed by entry into the fabrication-process scenes. Each scene contained a three-dimensional model and an explanation of the corresponding operation. The interface included a Start button, scene-navigation controls and sliders for rotation and scaling as shown in Fig. 3. C# scripts connected these controls to the application functions. Rotation changed the orientation of the displayed model, while scaling adjusted its visual size. Navigation controls allowed users to advance through the fabrication sequence and an exit control was provided at the end. This arrangement paired process information with a manipulable representation of the associated structure. The intended instructional function was to connect explanations with the intermediate stages of fabrication. The integrated Unity project was then exported as an APK and installed on an Android mobile device. Functional checking covered application launch, scene transitions, model and text presentation, and operation of the rotation and scaling controls. Identified errors were addressed through revisions and rebuilding. The technical assessment was limited to functional operation.

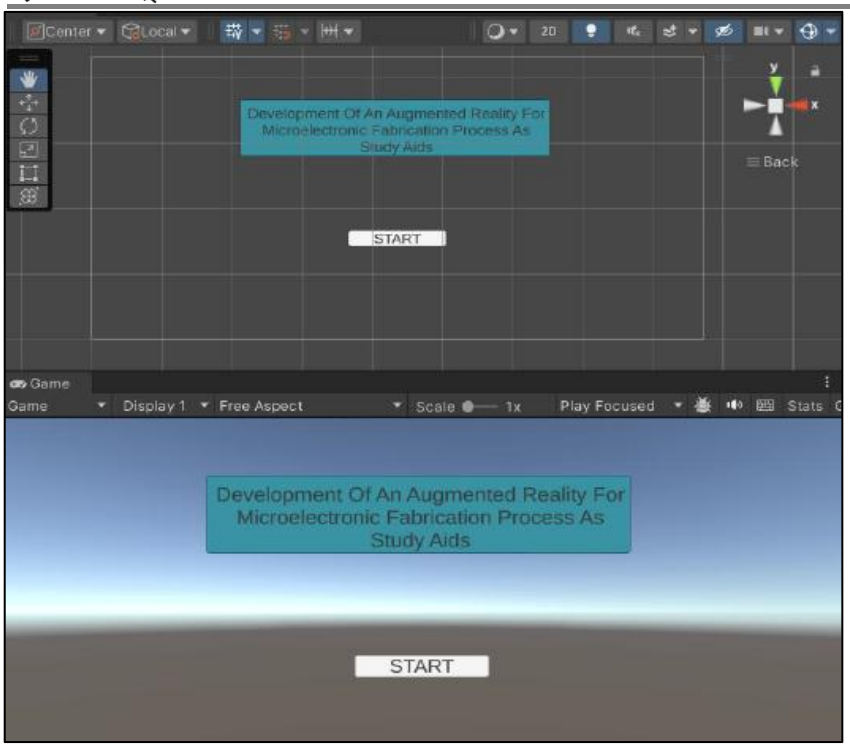


Fig. 3 Main Menu Page for the Microelectronics Fabrication AR Application.

4. Participants and Questionnaire

The user evaluation involved 18 engineering students from the engineering faculty. Fifteen respondents (83.3%) reported having taken a microelectronics-related course, while three (16.7%) had not. Six questionnaire statements addressed the provision of fabrication information, interest in the subject, ease of use, clarity of explanations, understandability of the three-dimensional representations and interactivity or enjoyment. Responses were summarised using the categories agree, slightly agree, neutral and disagree.

Additional questions collected an overall user-friendliness rating, a response concerning perceived academic improvement, and self-ratings of fabrication understanding before and after application use. User-friendliness and understanding were reported on five-point scales.

Responses were analysed descriptively using counts and percentages, with 18 respondents. Percentages were rounded to one decimal place. For discussion, agree and slightly agree were combined as favourable responses, while the individual categories were retained in the results table. The available data consisted of questionnaire summaries rather than participant-level records. Paired changes in understanding could therefore not be examined, and no inferential statistical tests were performed. Self-rated understanding and perceived academic improvement were interpreted as subjective responses, not verified changes in knowledge or assessment performance.

RESULTS AND ANALYSIS

Implemented Learning Prototype

The integration of AR in the study of microelectronics fabrication is successfully completed. The Android-based prototype integrated fabrication models, explanatory text and interaction controls within a sequence of application scenes. When using the application, users entered the sequence from the main menu, viewed the represented fabrication stages, adjusted model orientation and size, and advanced using the navigation controls.

The completed prototype integrated TinkerCAD models, Unity scenes, and C# scripts into a functional Android application. Fig. 4 shows the main menu and a representative deposition scene, where the fabrication model is presented alongside explanatory text linking the process to its corresponding structure. Sequential navigation organised the selected fabrication stages into a defined progression. Rotation and scaling controls allowed users to inspect the models from different orientations and at different display sizes. These controls modified the visual presentation without altering fabrication parameters. Similarly, scene transitions displayed successive structural stages without simulating the physical transformations between them. The application therefore provides interactive instructional representations of selected microelectronics fabrication processes.

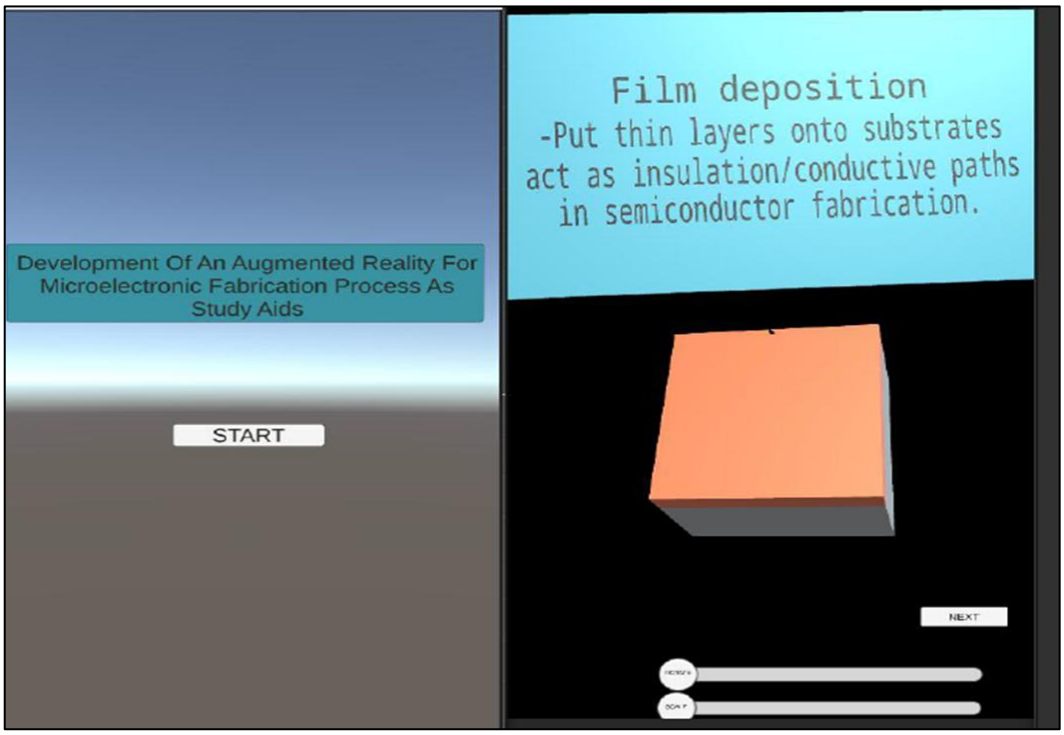


Fig. 4 Main Menu and Representative Deposition Scene Showing the Fabrication Model and Explanatory Text.

Information Delivery, Usability and Engagement

Table 2 summarises responses to six statements about the application experience. All respondents agreed that the application provided additional information on fabrication processes, with 14 (77.8%) selecting ‘agree’ and four (22.2%) selecting ‘slightly agree.’ This item received the highest proportion of favourable responses.

Table 2. Questionnaire Responses Concerning Application Experience.

Questionnaire Statement	Agree (%)	Slightly agree (%)	Neutral (%)	Disagree (%)
Provides additional fabrication information	77.8	22.2	0.0	0.0
Increases interest in fabrication processes	44.4	38.9	16.7	0.0
Easy to use	61.1	27.8	11.1	0.0
Delivers fabrication information clearly	55.6	33.3	11.1	0.0

3D process design is understandable	50.0	38.9	5.6	5.6
Interactive and enjoyable to use	77.8	16.7	5.6	0.0

Sixteen respondents (88.9%) agreed or slightly agreed that the application delivered fabrication information clearly. This finding indicates favourable perceptions of information delivery, although it does not establish whether participants correctly understood each process. Ease of use also received favourable responses from 16 respondents (88.9%), while two (11.1%) remained neutral. On a separate five-point user-friendliness scale, nine respondents (50.0%) selected 5, five (27.8%) selected 4, and four (22.2%) selected 3. Overall, 14 respondents (77.8%) selected one of the upper two rating points, suggesting favourable initial perceptions of the interface.

Regarding engagement, 15 respondents (83.3%) agreed or slightly agreed that the application increased their interest in fabrication processes, while 17 (94.4%) considered it interactive and enjoyable. Although favourable responses were more frequent for interactivity and enjoyment than for subject interest, this descriptive difference does not establish a statistically significant distinction between the two items. The three-dimensional representations were considered understandable by 16 respondents (88.9%), while one respondent (5.6%) remained neutral and one (5.6%) disagreed. These responses suggest that the visual presentation was accessible to most participants, while indicating a need to investigate potential difficulties experienced by individual users. The questionnaire did not identify whether these difficulties arose from model geometry, material identification, explanatory text or navigation. Follow-up interviews or task-based observations could provide more specific guidance for refinement.

In addition, participants also rated their understanding of fabrication processes before and after application use on a five-point scale. Before use, 14 respondents (77.8%) selected ratings of 3–5, while four (22.2%) selected ratings of 1–2. After use, all 18 respondents (100%) selected ratings of 3–5. This shift indicates a favourable change in self-assessed understanding. However, these grouped ratings do not establish the extent of individual improvement or demonstrate objectively measured learning gains.

Table 3. Distribution of Self-Rated Fabrication Understanding Before and After Application Use.

Understanding rating	**Before (%)**	**After (%)**
Low ratings (1–2)	22.2	0.0
Ratings 3–5	77.8	100.0

This distribution suggests a favourable change in respondents' assessment of their understanding. Fifteen respondents (83.3%) also reported noticing academic improvement, while three (16.7%) did not. This is evidence of perceived improvement only: no examination scores, marked assessments or control-group comparisons. The finding therefore indicates perceived improvement only and cannot be attributed to the application.

The combined presentation of models, explanations and viewing controls offers a possible explanation for the favourable responses. Nevertheless, the study did not isolate the contribution of individual features or compare

the application with conventional resources. The results support further investigation of the approach rather than a conclusion that it improves learning.

Educational Implications and Limitations

The AR prototype illustrates a practical way to present selected microelectronics fabrication stages through mobile AR. Its sequential structure could be used during demonstrations or review activities in which students identify material layers, explain process functions and compare intermediate structures. The questionnaire findings indicate that most participants considered the application informative, usable and engaging, providing a basis for refining the resource.

Several limitations should be considered when interpreting these findings. The evaluation involved 18 students from a single faculty, which limits the generalisability of the results. Furthermore, the available documentation did not establish whether the before-use understanding ratings were collected before application use or retrospectively afterward. The reported changes therefore reflect self-assessed understanding and should not be interpreted as verified pre-test–post-test learning gains.

CONCLUSION

This study developed and conducted an initial user evaluation of a markerless augmented reality application for learning selected microelectronics fabrication processes. Simplified three-dimensional models were created in TinkerCAD, integrated into Unity with C# scripts, and deployed as an Android application. The prototype combined sequential navigation and explanatory text with rotation and scaling controls, providing interactive representations of selected fabrication stages.

Questionnaire responses from 18 engineering students indicated favourable initial acceptance. Combined agreement and slight agreement reached 88.9% for ease of use and 94.4% for interactivity and enjoyment. Self-rated understanding also shifted towards higher response categories following application use. These findings suggest perceived instructional value; however, the small sample, reliance on self-reported responses, and absence of a controlled knowledge assessment prevent conclusions about actual improvements in learning or academic achievement.

The study demonstrates the feasibility of integrating fabrication models and process explanations into a supplementary mobile AR learning resource. Future development should prioritise subject-specialist review, clearer visual transitions between fabrication stages, and structured usability testing. Quantitative technical testing and controlled educational evaluation using a validated concept assessment would help establish the application’s reliability and effectiveness in supporting microelectronics learning.

ACKNOWLEDGMENT

We would like to thank Universiti Teknikal Malaysia Melaka (UTeM) for for providing the facilities and workspace in Faculty of Electronics & Computer Technology & Engineering. We would also like to thank the students who participated in the application testing and questionnaire evaluation.

REFERENCES

1. Antonioli, M., Blake, C., & Sparks, K. (2014). Augmented reality applications in education. The Journal of technology studies, 96-107.
2. Gao, Q. H., Wan, T. R., Tang, W., & Chen, L. (2017). A stable and accurate marker-less augmented reality registration method. 2017 International Conference on Cyberworlds (CW),
3. Ismail, M. E., Utami, P., Ismail, I. M., Khairudin, M., Amiruddin, M. H., Lastariwati, B., & Maneetien, N. (2018). The effect of an augmented reality teaching kit on visualization, cognitive load and teaching styles. Jurnal Pendidikan Teknologi dan Kejuruan, 24(2), 178-184.

4. Noh, K.-H., Jee, H.-K., & Lim, S.-H. (2010). Effect of augmented reality contents based instruction on academic achievement, interest and flow of learning. The Journal of the Korea Contents Association, 10(2), 1-13.
5. Pooja, J., Vinay, M., Vineetha, G. P., & Anuradha, M. (2020). Comparative analysis of marker and marker-less augmented reality in education. 2020 IEEE International Conference for Innovation in Technology (INOCON),
6. Silver, E. A. (2013). Using conceptual and procedural knowledge: A focus on relationships. In Conceptual and procedural knowledge (pp. 181-198). Routledge.
7. Singh, N., Srivastava, K., Kumar, A., Yadav, N., Yadav, A., Dubey, S., Singh, R., Gehlot, A., Verma, A. S., & Gupta, N. (2024). Challenges and opportunities in engineering next-generation 3D microelectronic devices: improved performance and higher integration density. Nanoscale advances, 6(24), 6044-6060.
8. Tekedere, H., & Göke, H. (2016). Examining the effectiveness of augmented reality applications in education: A meta-analysis. International Journal of Environmental and Science Education, 11(16), 9469-9481.
9. Turan, Z., & Atila, G. (2021). Augmented reality technology in science education for students with specific learning difficulties: Its effect on students' learning and views. Research in Science & Technological Education, 39(4), 506-524.
10. Yildiz, E. P. (2022). Augmented Reality Applications in Education: Arloopa Application Example. Higher Education Studies, 12(2), 47-53.