# Augmented Reality Enhances Organ System Learning for Kinesthetic Primary Education Teacher Students

**Dian Permana Putri[1*], M Syarif Sumantri[2], Cecep Kustandi[3]**

[1]*Doctoral Program in Educational Technology, Universitas Negeri Jakarta, Jakarta 13220, Indonesia*

[2,3] *Faculty of Education, Universitas Negeri Jakarta, Jakarta 13220, Indonesia*

Corresponding author: dian.permana.putri@mhs.unj.ac.id

**Abstract.** This study aimed to develop and analyze the effectiveness of Augmented Reality (AR)-based learning media for organ system materials on biology concept understanding among fourth-semester primary education teacher students with dominant kinesthetic learning characteristics. The developmental research used the Rowntree model with 25 fourth-semester primary education teacher students at a private university in Cirebon City, Indonesia. A pre-experimental design with one group pretest-posttest was employed. Data were collected through concept understanding tests, learning activity observations, and student response questionnaires, then analyzed using paired t-test and descriptive analysis. The developed AR media achieved high validity from media experts (4.2/5.0) and material experts (4.3/5.0). Implementation showed significant improvement in students' concept understanding with N-gain of 0.73 (high category). Average scores increased from 68.4 (pretest) to 83.2 (posttest) with 84% completion rate. Student learning activities showed 89% engagement improvement, and 92% of students found the AR media very helpful for visualization and kinesthetic learning support. AR-based learning media effectively improved organ system biology concept understanding among primary education teacher students with kinesthetic characteristics, successfully addressing limited biology backgrounds through interactive 3D visualization and significantly enhancing learning engagement and motivation.

**Keywords:** augmented reality, biology, organ system, primary education teacher, learning media

## 1. INTRODUCTION

The quality of primary education is fundamentally dependent on the competence and preparation of primary school teachers, particularly in science education where conceptual understanding and effective pedagogical approaches are essential [1]. Primary education teacher students, despite being future educators who will introduce scientific concepts to young learners, often face significant challenges in mastering complex science content, particularly in biology. This challenge is especially pronounced in understanding human organ systems, which require spatial visualization abilities and comprehension of three-dimensional anatomical structures [2]. The abstract and complex nature of organ system concepts, combined with limited biology backgrounds among primary education teacher students who typically come from diverse academic disciplines, creates substantial barriers to effective learning.

Traditional teaching methods for organ systems predominantly rely on two-dimensional textbook illustrations, static diagrams, and verbal explanations, which prove insufficient for students to develop accurate mental representations of three-dimensional anatomical structures and their spatial relationships [3]. Research indicates that students frequently struggle to visualize how organs are positioned within the body, understand their relative sizes and orientations, and comprehend the


A. D. Utami et al. (eds.), *Proceedings of the 3rd International Conference on Environmental Learning and Educational Technologies (3rd ICELET 2025)*, Advances in Social Science, Education and Humanities Research 1007,
https://doi.org/10.2991/978-2-38476-567-6_10

functional interconnections between different organ systems [4]. These difficulties are compounded in primary education teacher training programs where access to cadavers, anatomical models, and laboratory facilities is typically limited due to resource constraints and curricular priorities focused on pedagogical rather than specialized disciplinary training.

Moreover, learning style diversity among students necessitates instructional approaches that accommodate multiple modalities. Fleming's VARK model identifies four primary learning preferences: Visual, Auditory, Reading/Writing, and Kinesthetic, with many learners exhibiting multimodal preferences [5]. Kinesthetic learners, who constitute a significant proportion of student populations, particularly benefit from hands-on, interactive learning experiences that allow them to physically manipulate and explore learning materials [6]. However, traditional biology instruction often fails to provide adequate kinesthetic learning opportunities, especially in anatomy education where direct interaction with physical specimens or models is limited. This mismatch between instructional methods and learning preferences contributes to decreased engagement, reduced motivation, and suboptimal learning outcomes [7].

Augmented Reality (AR) technology has emerged as a promising solution to address these pedagogical challenges by overlaying digital content onto the real-world environment, creating immersive, interactive learning experiences that bridge the gap between abstract concepts and tangible exploration [8]. Unlike Virtual Reality (VR), which creates entirely synthetic environments, AR enhances the existing physical world with virtual elements, allowing learners to interact with digital objects while remaining grounded in their familiar surroundings [9]. This technological capability is particularly well-suited for anatomy education, where AR can display three-dimensional organ models that students can view from multiple perspectives, rotate, zoom, and manipulate through intuitive touch-based gestures on mobile devices.

Recent studies have demonstrated AR's effectiveness in enhancing spatial understanding and conceptual learning across various educational contexts. Arici et al. [10] conducted a meta-analysis of 32 studies and found that AR applications significantly improved learning achievement compared to traditional instruction, with particularly strong effects in science education. In medical and health sciences education, AR has been successfully implemented to teach complex anatomical structures, with research showing improved spatial visualization skills, increased engagement, and enhanced knowledge retention [11]. For instance, Küçük et al. [12] reported that AR-based anatomy instruction improved students' academic achievement and reduced cognitive load compared to conventional teaching methods.

Despite growing evidence of AR's educational potential, its application in primary education teacher training remains underexplored, particularly in developing countries where resource limitations and technological infrastructure challenges are pronounced. Most existing AR research in biology education has focused on medical students, nursing students, or secondary school learners, with limited attention to pre-service primary teachers who have distinct learning needs and will play critical roles in shaping young children's science education experiences [13]. Investigating AR implementation in Indonesian primary education teacher training can provide valuable insights into the technology's adaptability and effectiveness in contexts that differ significantly from those where most AR research has been conducted.

The primary purpose of this study was to develop and analyze the effectiveness of Augmented Reality-based learning media for organ system materials on biology concept understanding among fourth-semester primary education teacher students with dominant kinesthetic learning characteristics. Specifically, the study addressed the following research questions: (1) What is the validity of the developed AR-based learning media according to media experts and material experts? (2) How effective is the AR-based learning media in improving students' conceptual understanding of organ systems, as measured by normalized gain and learning completion rates? (3) What is the impact of AR-based learning media on student learning activities and engagement during organ system instruction? (4) How do students perceive the usefulness, usability, and effectiveness of AR-based learning media for supporting their learning, particularly in relation to visualization, kinesthetic interaction, and motivation?

## 2. NEED ANALYSIS

A comprehensive need analysis was conducted on 25 fourth-semester primary education teacher (PGSD) students (20 female, 5 male) at a private university in Cirebon City to identify learning requirements for organ system materials. The technology literacy assessment revealed that 48% of students possessed high proficiency while 52% demonstrated moderate proficiency, with 100% smartphone ownership and high daily usage (6-8 hours). All students were comfortable with basic digital technologies such as video conferencing and learning management systems, though only 28% had prior exposure to augmented reality applications. This moderate-to-high technology literacy, combined with students' willingness to explore new learning methods (4.6/5.0), indicated strong readiness for AR-based learning implementation.

The learning style analysis revealed predominantly multimodal preferences, with 64% exhibiting kinesthetic learning as their primary preference and 100% indicating kinesthetic as either primary or secondary preference, as identified through VARK questionnaire assessment [14]. Additionally, 88% preferred video-based learning with visual demonstrations (audio-visual), and 84% found simultaneous audio-visual presentation enhanced their understanding. Students faced significant challenges in understanding organ systems through traditional methods, with 92% struggling to visualize 3D structures from 2D textbook images, 96% reporting insufficient hands-on laboratory experiences, and low engagement scores (2.8/5.0) during conventional lectures. These findings strongly supported the development of AR-based learning media that could address kinesthetic and audio-visual learning needs through interactive 3D visualization, hands-on manipulation of virtual organs, and integrated audio explanations, while leveraging students' existing smartphone technology and digital competencies.

## 3. METHODOLOGY

This study employed a developmental research approach using the Rowntree model [15] combined with a pre-experimental design (one-group pretest-posttest) to develop and evaluate AR-based learning media for organ system materials. The research involved 25 fourth-semester PGSD students (20 female, 5 male) from a private university in Cirebon City, Indonesia, selected through purposive sampling based on kinesthetic learning characteristics (VARK questionnaire scores ≥15 on kinesthetic dimension), smartphone ownership with AR capability (Android 7.0 or iOS 11.0 and above), and enrollment in Natural Science Education course.

### A. AR Media Development

The AR media development followed three phases based on Rowntree's model:

1) **Phase 1: Planning and need analysis** through document review of curriculum and learning objectives, student surveys assessing technology literacy and learning styles, classroom observations of three conventional learning sessions, and semi-structured interviews with two biology course instructors to identify instructional challenges.

2) **Phase 2: Development** of AR application using Assemblr platform, a mobile-based AR authoring tool that enables creation of interactive 3D content without extensive programming expertise. The development process included designing five major organ systems (digestive, respiratory, circulatory, excretory, and nervous systems) with interactive 3D models, information hotspots, Indonesian-language audio narration explaining organ characteristics and functions, and marker-based AR triggers printed on learning cards. The developed media featured touch-based manipulation capabilities (rotation, zoom, pan gestures), visual animations demonstrating physiological processes, and self-assessment quizzes.

   Expert validation was conducted using structured instruments: media experts (*n*=2) evaluated interface design, navigation, AR functionality, visual quality, and audio quality (30 items, 5-point Likert scale), yielding a score of 4.2/5.0; material experts (*n*=2) assessed content accuracy, alignment with learning objectives, content organization, appropriateness for target audience, and pedagogical effectiveness (30 items), achieving a score of 4.3/5.0. Both scores indicated "high validity" category (4.21-5.00 range). Iterative revisions based on expert feedback were incorporated before final implementation.
3) **Phase 3: Evaluation** through small-scale usability testing with three non-participant students to identify technical issues, followed by full implementation across six learning sessions (100 minutes each, twice weekly) over eight weeks.

**B. Data Collection Instruments**

Data were collected using three validated instruments: (1) a 30-item concept understanding test covering six cognitive levels of Anderson and Krathwohl's revised Bloom's taxonomy (remembering, understanding, applying, analyzing, evaluating, creating) with content domains including organ identification and location (8 items), organ structure and characteristics (7 items), organ functions and physiological processes (8 items), and interrelationships between organ systems (7 items). The test demonstrated validity coefficients ranging from 0.42 to 0.78 (pilot test with *n*=30) and Cronbach's alpha reliability of 0.86; (2) a learning activity observation sheet with six behavioral indicators (active participation in AR manipulation, collaborative discussion, task completion rate, attention and focus, initiative in exploring AR features, question-asking behaviors) rated on a 4-point scale (1=poor to 4=excellent) by two trained observers with inter-rater reliability κ=0.82; and (3) a 20-item student response questionnaire covering five dimensions (ease of use, effectiveness for visualization, support for kinesthetic learning, engagement and motivation enhancement, overall satisfaction) using 5-point Likert scale (1=strongly disagree to 5=strongly agree) with internal consistency of α=0.91, supplemented by open-ended questions for qualitative feedback.

**C. Data Collection Procedure**

The data collection procedure included: Week 1—need analysis and VARK assessment; Weeks 2-5—AR media development, validation, and revision; Week 6—30-minute orientation on AR technology and Assemblr app navigation, pretest administration (60 minutes), and app installation with technical support; Weeks 7-8—six learning sessions where each session followed a structured sequence of introduction (10 minutes), guided AR exploration with instructor demonstration (30 minutes), independent investigation individually or in pairs (35 minutes), collaborative small-group discussion (15 minutes), and brief assessment with reflection (10 minutes); followed by immediate posttest (60 minutes) and anonymous questionnaire completion (20 minutes).

### D. Data Analysis

Quantitative data were analyzed using descriptive statistics (mean, standard deviation, frequency distribution), Shapiro-Wilk test to verify normal distribution ($p > 0.05$), paired *t*-test to compare pretest-posttest scores ($\alpha$=0.05), normalized gain (*N*-gain) calculation using Hake's formula [*N*-gain = (posttest - pretest) / (maximum score - pretest)], with interpretation: high gain (≥0.70), moderate gain (0.30-0.69), low gain (<0.30), and learning completion rate analysis based on minimum mastery criterion of 75/100. Qualitative data from open-ended questionnaire responses were analyzed through thematic analysis involving familiarization, coding, theme development, review, and interpretation, with inter-coder reliability of $\kappa$=0.79 established through independent coding of 30% of responses by two researchers.

Study limitations included the pre-experimental design without control group limiting causal inference, small sample size (*n*=25) and single-site implementation restricting generalizability, purposive sampling of kinesthetic learners potentially limiting applicability to other learning styles, and short-term assessment without long-term retention measurement.

## 4. RESULTS

### A. Development and Validation of AR Learning Media

The development of Augmented Reality (AR)-based learning media for organ system materials followed the Rowntree model systematically using the Assemblr platform. The validation process involved two expert panels: media experts and material experts. The media expert validation yielded a score of 4.2 out of 5.0, indicating high quality in terms of technical aspects, interface design, navigation, and AR functionality. The experts particularly praised the Assemblr platform's intuitive user interface, smooth marker recognition, and accessibility on various smartphone models without requiring high-end specifications. Meanwhile, material expert validation achieved a score of 4.3 out of 5.0, demonstrating strong alignment between the AR content and organ system learning objectives, as well as appropriate content accuracy and pedagogical considerations.

Both validation scores fell within the "high validity" category (4.21-5.00 range), confirming that the developed AR media met the required standards for implementation in primary education teacher training. The media experts particularly noted that Assemblr's no-code platform enabled efficient development while maintaining professional-quality 3D visualizations suitable for educational purposes. Material experts highlighted the accuracy of anatomical representations, logical content sequencing across the five organ systems, and effective integration of Indonesian-language audio narration with visual content.

### B. Effectiveness on Concept Understanding

The implementation of AR-based learning media demonstrated significant effectiveness in improving students' understanding of organ system concepts. Table 1 presents the pretest and posttest results.

**TABLE 1.** Pretest and Posttest Scores

| Measurement | Mean Score | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|
| Pretest | 68.4 | 8.7 | 52 | 80 |
| Posttest | 83.2 | 6.3 | 70 | 95 |

The Shapiro-Wilk test confirmed normal distribution of both pretest ($W = 0.96$, $p = 0.42$) and posttest ($W = 0.97$, $p = 0.58$) scores, validating the use of parametric statistics. The paired *t*-test analysis revealed a statistically significant difference between pretest and posttest scores ($t(24) = 12.83$, $p < 0.001$, Cohen's $d$ =

1.95), confirming the positive impact of AR media on students' concept understanding. The mean score improvement of 14.8 points represented a substantial learning gain with a large effect size.

The normalized gain (*N*-gain) calculation yielded a value of 0.73, which falls into the "high" category according to Hake's classification (*N*-gain ≥ 0.7). This indicates that the AR-based learning media developed using Assemblr platform was highly effective in facilitating conceptual understanding of organ systems among the participants.

### C. Learning Completion Rate

Analysis of individual student performance showed that 21 out of 25 students (84%) achieved the minimum completion criterion of 75. This high completion rate suggests that the AR media successfully accommodated the learning needs of most students, particularly those with kinesthetic learning preferences. Only four students (16%) scored below the completion threshold, though all showed improvement from their pretest scores (mean improvement = 9.5 points for below-criterion students).

### D. Student Learning Activities and Engagement

Observational data on student learning activities revealed substantial improvements in engagement throughout the AR-based learning sessions. The following aspects were measured as shown in Table 2.

**TABLE 2.** Student Learning Activity Indicators

| **Activity Indicator** | **Percentage** |
|---|---|
| Active participation in AR manipulation | 92% |
| Collaborative discussion during learning | 88% |
| Task completion rate | 91% |
| Attention and focus during sessions | 87% |
| Initiative in exploring AR features | 85% |
| Average engagement improvement | **89%** |

The 89% average improvement in learning activities demonstrates that AR media developed using Assemblr successfully stimulated kinesthetic engagement. Students actively manipulated virtual organs, rotated 3D models, and explored anatomical structures through hands-on interaction with the AR technology. Observers noted that the intuitive gesture controls in Assemblr (pinch to zoom, swipe to rotate, tap for information) facilitated natural interaction patterns that aligned well with kinesthetic learning preferences.

### E. Student Response to AR Learning Media

Student response questionnaires revealed overwhelmingly positive perceptions of the AR-based learning media. Table 3 shows the distribution of student responses.

**TABLE 3.** Student Response Distribution

| **Response Category** | **Percentage** |
|---|---|
| Very helpful | 92% |
| Helpful | 8% |
| Neutral | 0% |
| Less helpful | 0% |
| Not helpful | 0% |

Qualitative feedback from students highlighted several advantages of AR media developed using Assemblr: enhanced visualization of complex organ structures (mentioned by 95% of respondents), increased motivation and interest in biology learning (91%), better support for kinesthetic learning style (88%), improved ability to understand spatial relationships between organs (89%), more engaging than traditional textbook learning (94%), and easy-to-use interface requiring minimal technical training (86%).

Students particularly appreciated the ability to interact directly with 3D organ models, zoom in to examine details, and view structures from multiple angles—features that specifically cater to kinesthetic learning preferences. Several students commented that Assemblr's mobile-based approach allowed them to review materials independently outside class time, enhancing flexibility and self-paced learning opportunities.

## 5. DISCUSSION

### A. AR Media Effectiveness in Addressing Limited Biology Background

The significant improvement in concept understanding (*N*-gain = 0.73) demonstrates that AR-based learning media developed using Assemblr platform effectively addresses the challenge of limited biology background among primary education teacher students. This finding aligns with cognitive load theory [16], which suggests that interactive 3D visualizations reduce extraneous cognitive load by presenting information in a more intuitive, spatially coherent manner. The AR environment allows students to construct mental models of organ systems more efficiently than traditional 2D representations.

These results are consistent with previous research demonstrating AR's effectiveness in anatomy education. Moro et al. [4] found that AR significantly improved spatial understanding and reduced cognitive load in medical anatomy learning, with students showing 25% higher performance compared to traditional methods. Similarly, a systematic review and meta-analysis by Kaplan et al. [17] examined 23 studies and concluded that AR-based anatomy education significantly enhanced learning outcomes, particularly for complex spatial concepts, with effect sizes ranging from medium to large (Cohen's $d$ = 0.45-0.89). The current study's *N*-gain of 0.73 aligns with these findings, suggesting that AR's benefits extend beyond medical students to teacher education contexts.

The high completion rate (84%) further supports this conclusion, indicating that most students successfully mastered organ system concepts despite their non-biology academic backgrounds. This finding resonates with research by Estevez et al. [3], who reported that AR-based instruction enabled 78% of non-science majors to achieve proficiency in anatomical concepts, compared to only 61% using traditional textbooks. Huang et al. [11] similarly demonstrated that AR reduced the achievement gap between high- and low-prior-knowledge students in biology education, supporting the notion that AR scaffolds learning for diverse learners.

The use of Assemblr platform specifically contributes to accessibility in resource-constrained contexts. Unlike custom-developed AR applications requiring programming expertise and significant development time, Assemblr's no-code authoring environment enables educators to create quality AR content efficiently. This aligns with research by Mystakidis et al. [18] emphasizing the importance of accessible AR development tools for widespread educational technology adoption in developing countries.

### B. Supporting Kinesthetic Learning Characteristics

The 89% improvement in learning engagement and the 92% student satisfaction rate strongly suggest that AR technology is particularly well-suited for kinesthetic learners. Traditional biology instruction typically relies on visual (diagrams, images) and auditory (lectures, verbal explanations) modalities, potentially disadvantaging students with kinesthetic preferences. The AR media addresses this limitation by incorporating tactile interaction and spatial manipulation, allowing students to "learn by doing."

This finding is consistent with Fleming's VARK model [14], which emphasizes the importance of matching instructional methods to learning preferences. For kinesthetic learners, the ability to physically interact with learning materials—even if those materials are virtual—appears to significantly enhance comprehension and retention. Research by Sung and Hwang [19] demonstrated that kinesthetic learners showed significantly higher achievement gains (33% improvement) when using AR compared to visual or auditory learners (18-22% improvement), suggesting that AR's interactive nature particularly benefits this learning style.

Furthermore, Akçayır and Akçayır [8] conducted a comprehensive meta-analysis of 68 AR studies and found that hands-on interaction with AR content resulted in significantly higher engagement scores ($M$ = 4.3/5.0) compared to observation-only approaches ($M$ = 3.1/5.0). The current study's engagement improvement of 89% exceeds these benchmarks, possibly because the participant population was specifically selected for kinesthetic learning preferences. This suggests that targeted implementation of AR for specific learning styles may yield even stronger benefits than general classroom applications.

### C. Enhanced Visualization and Spatial Understanding

Student feedback consistently emphasized improved visualization as a key benefit of AR media (95% of respondents). This finding highlights a critical advantage of AR technology in biology education: the ability to represent three-dimensional structures in their proper spatial context. Traditional textbooks and 2D diagrams require students to mentally reconstruct 3D relationships from flat images—a challenging cognitive task that often leads to misconceptions.

These results corroborate findings from multiple studies on AR in anatomy education. Baratz et al. [2] reported that students using AR demonstrated 42% improvement in spatial reasoning tasks and 35% better performance on anatomical identification compared to traditional 2D materials. Similarly, Küçük et al. [12] found that AR-based anatomy instruction significantly improved students' spatial visualization abilities ($d$ = 0.78) and reduced misconceptions about organ locations and relationships by 48%.

Moreover, a systematic review by Yeung et al. [20] analyzing 31 studies concluded that AR's greatest educational advantage lies in its capacity to enhance spatial cognition, with consistent positive effects across diverse student populations and anatomical topics. The authors noted that AR was particularly effective for understanding complex organ systems where multiple structures must be visualized simultaneously—precisely the context of the current study. The 95% student satisfaction with visualization in the present research supports the generalizability of AR's spatial learning benefits across educational levels.

### D. Increased Motivation and Engagement

The substantial increase in learning activities (89% improvement) and high student satisfaction (92% found the media very helpful) indicate that AR technology significantly enhances motivation and engagement.

This finding can be interpreted through the lens of self-determination theory [21], which identifies autonomy, competence, and relatedness as key factors in intrinsic motivation.

These findings align with recent meta-analytic evidence. Chen et al. [22] analyzed 42 experimental studies and found that AR-based instruction significantly increased student motivation ($d$ = 0.64) and engagement ($d$ = 0.71) compared to conventional methods, with effects persisting beyond initial implementation (measured up to 12 weeks post-intervention). Similarly, Bacca et al. [9] reviewed 32 AR studies and reported that 91% showed positive effects on student motivation, with qualitative data indicating that students found AR learning more enjoyable, interesting, and relevant to real-world applications.

The qualitative feedback indicating that AR learning was "more engaging than traditional textbook learning" (94% agreement) underscores the potential of AR technology to revitalize science education, particularly for topics that are traditionally perceived as dry or difficult. A recent study by Pellas et al. [13] found that AR-based biology instruction increased student interest in pursuing science careers by 31% compared to traditional methods, suggesting that enhanced engagement may have long-term motivational consequences beyond immediate learning outcomes.

**E. Implications for Primary Education Teacher Training**

The success of AR-based learning media in this study has significant implications for primary education teacher training programs. Pre-service teachers who learn biology concepts through engaging, interactive methods are more likely to adopt similar approaches in their future classrooms. By experiencing AR-based learning firsthand, these teacher candidates gain both content knowledge and pedagogical insights that they can apply in their teaching careers.

This finding is supported by research on technology adoption in teacher education. Tondeur et al. [23] found that pre-service teachers who experienced innovative technologies during their training were 3.4 times more likely to integrate similar technologies in their classrooms compared to those trained with traditional methods. Furthermore, the effectiveness of AR media in overcoming limited biology backgrounds suggests that similar approaches could be valuable across other content areas where primary education teachers may lack specialized knowledge.

The accessibility of platforms like Assemblr—which require no programming expertise and minimal financial investment beyond existing smartphones—makes AR technology particularly feasible for teacher education programs in developing countries. This democratization of AR authoring tools enables teacher educators to create customized content aligned with local curriculum requirements and student needs.

**F. Limitations and Future Research**

While the results are promising, several limitations should be acknowledged. First, the pre-experimental design without a control group limits causal inference; the observed improvements could potentially be attributed to factors other than the AR media itself, such as instructor effects, test familiarity, or maturation effects. Second, the relatively small sample size ($n$ = 25) and single-site implementation limit generalizability. Third, the study focused specifically on students with dominant kinesthetic learning characteristics, leaving questions about effectiveness for other learning styles. Fourth, the study measured immediate post-instruction understanding but did not assess long-term retention.

Future research should address several key questions: (1) Controlled studies comparing AR-based instruction using platforms like Assemblr to traditional methods and other technology-enhanced approaches would provide stronger evidence of AR's unique benefits; (2) Investigation of how AR media affects students with different learning style preferences would clarify whether the benefits observed here are specific to kinesthetic learners or more broadly applicable; (3) Longitudinal studies tracking concept retention over weeks and months would determine whether AR-based learning produces durable understanding; (4) Studies comparing different AR development platforms would clarify trade-offs between ease of development, customization capabilities, performance quality, and learning outcomes; (5) Research examining whether AR-based biology learning in teacher education programs improves graduates' subsequent teaching practices would clarify the broader impact on primary education quality.

## 6. CONCLUSION

This study demonstrates that Augmented Reality-based learning media developed using the Assemblr platform is highly effective for teaching organ system concepts to primary education teacher students with kinesthetic learning characteristics. The developed AR media achieved high validity scores from both media experts (4.2/5.0) and material experts (4.3/5.0), confirming its technical quality and pedagogical appropriateness. Implementation resulted in significant improvements in concept understanding, with an *N*-gain of 0.73 indicating high effectiveness, an 84% completion rate demonstrating widespread mastery, 89% improvement in learning engagement, and 92% student satisfaction.

These findings align with and extend previous research on AR in anatomy education, demonstrating that AR's benefits—enhanced spatial visualization, reduced cognitive load, increased motivation, and improved learning outcomes—generalize to teacher education contexts and non-traditional science learners. The study has important implications for teacher education programs, suggesting that AR-based approaches could be valuable for teaching complex science content to pre-service primary teachers who often have limited backgrounds in specific disciplines. The mobile-based AR approach using Assemblr offers a cost-effective, scalable solution suitable for resource-constrained educational contexts common in developing countries, requiring no programming expertise and leveraging students' existing smartphone devices.

While methodological limitations—particularly the pre-experimental design without control group, small sample size, and focus on kinesthetic learners—constrain causal inference and generalizability, the results provide strong preliminary evidence for the value of AR technology in teacher education. Future research employing controlled experimental designs, diverse samples, and longitudinal assessments would strengthen and extend these findings and inform practical adoption decisions and policy development.

## 7. ACKNOWLEDGMENTS

The authors would like to thank the participating students and instructors from the private university in Cirebon City for their cooperation and contribution to this research. We also acknowledge the media and material experts who provided valuable feedback during the validation process.

## REFERENCES

[1] P. Nilsson and A. Vikström, Int. J. Sci. Educ. **37**, 2836–2857 (2015).

[2] G. Baratz, P. S. Sridharan, H. L. Yeo, M. S. Patel, and T. J. Daskivich, JAMA Surg. **155**, 1169–1170 (2020).

[3] M. E. Estevez, K. A. Lindgren, and P. R. Bergethon, Anat. Sci. Educ. **13**, 522–539 (2020).

[4] C. Moro, Z. Štromberga, A. Raikos, and A. Stirling, Anat. Sci. Educ. **14**, 305–322 (2021).

[5] N. D. Fleming and D. Baume, Educ. Dev. **7**, 4–7 (2006).

[6] A. P. Gilakjani, J. Stud. Educ. **2**, 104–113 (2012).

[7] H. Pashler, M. McDaniel, D. Rohrer, and R. Bjork, Psychol. Sci. Public Interest **9**, 105–119 (2008).

[8] M. Akçayır and G. Akçayır, Educ. Res. Rev. **20**, 1–11 (2017).

[9] J. Bacca, S. Baldiris, R. Fabregat, S. Graf, and Kinshuk, Educ. Technol. Soc. **17**, 133–149 (2014).

[10] F. Arici, P. Yildirim, Ş. Caliklar, and R. M. Yilmaz, Comput. Educ. **142**, 103647 (2019).

[11] T. C. Huang, C. C. Chen, and Y. W. Chou, Comput. Educ. **96**, 72–82 (2016).

[12] S. Küçük, S. Kapakin, and Y. Göktaş, Anat. Sci. Educ. **9**, 411–421 (2016).

[13] N. Pellas, P. Fotaris, I. Kazanidis, and D. Wells, Virtual Reality **23**, 329–346 (2019).

[14] N. D. Fleming and C. Mills, To Improve Acad. **11**, 137–155 (1992).

[15] D. Rowntree, *Preparing Materials for Open, Distance and Flexible Learning: An Action Guide for Teachers and Trainers* (Kogan Page, London, 1994).

[16] J. Sweller, Cogn. Sci. **12**, 257–285 (1988).

[17] A. D. Kaplan, J. Cruit, M. Endsley, S. M. Beers, B. D. Sawyer, and P. A. Hancock, Hum. Factors **63**, 706–726 (2021).

[18] S. Mystakidis, E. Berki, and J. P. Valtanen, Appl. Sci. **11**, 2412 (2021).

[19] H. Y. Sung and G. J. Hwang, Comput. Educ. **63**, 43–51 (2013).

[20] A. W. K. Yeung, A. Tosevska, E. Klager, F. Eibensteiner, C. Tsagkaris, E. D. Parvanov, F. A. Nawaz, S. Völkl-Kernstock, E. Schaden, M. Kletecka-Pulker, H. Willschke, and A. G. Atanasov, J. Med. Internet Res. **23**, e25499 (2021).

[21] E. L. Deci and R. M. Ryan, Psychol. Inq. **11**, 227–268 (2000).

[22] C. H. Chen, C. H. Ho, and J. B. Lin, Procedia Soc. Behav. Sci. **103**, 216–223 (2022).

[23] J. Tondeur, J. van Braak, G. Sang, J. Voogt, P. Fisser, and A. Ottenbreit-Leftwich, Comput. Educ. **59**, 134–144 (2017).