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Digital literacy: How mobile augmented reality titration in acid-base titrations facilitated the skill

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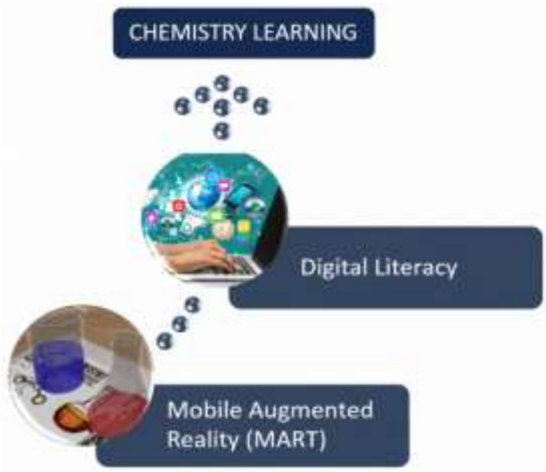
Abstract

Augmented reality media is used in chemistry education to enhance digital literacy skills, which are essential for higher education in the twenty-first century, and to provide titration simulations that reduce the need for chemicals. By producing media based on augmented reality and facilitating the understanding of acid-base titration, this initiative aims to enhance students' digital literacy. A product called Mobile Augmented Reality Titration (MART) was created by implementing the Ploomp approach. Content validation demonstrates the high legitimacy and validity of the produced media. A post-test group design research study with 60 participants, split between control and experimental classes, was used to gauge the effectiveness of digital literacy abilities. The empirical test findings found a substantial difference in digital literacy skills between the experimental and control groups, as indicated by Cohen's D value of 3.85. This suggests that the rise of augmented reality media has substantially impacted the ability to learn acid-base titrations through digital literacy.



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1. technology-enhanced learning;
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3. chemical literacy;
4. personalized learning;
5. digitalized learning in chemistry.

Section Editors

Natany Dayani de Souza **Assai**

Highlights

- An augmented reality application to support acid-base titration practice.
- Development of MART media through Ploomp design.
- Functional skills, creativity, and communication are essential abilities.
- Digital literacy involves selecting, engaging with, and evaluating information.

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1. Introduction

Digital literacy is an important aspect of supporting 21st-century learning that needs to be practiced and developed. (Chaiyama, 2019). Digital literacy skills are closely related to the ability to understand and utilize digital technology in everyday life, which is highly essential in today's global world (Lankshear and Knobel, 2008; Rahmi *et al.*, 2022). Several related studies report that increasing digital literacy skills has a direct impact on creative thinking abilities and student learning outcomes (Kesici, 2022; Nadila *et al.*, 2022; Tarumasely, 2022). Paul Gilster (2008) explains that individuals with good digital literacy skills can effectively search for the information they need using the internet and hypertext to read texts. Subsequently, they can evaluate and select relevant digital information according to their needs. Ultimately, they can organize knowledge and compile information to create new insights and understanding. This ability significantly supports the learning experience and is crucial in enhancing student learning outcomes (Gilster, 1997).

Numerous studies have been conducted to measure digital literacy skills (Adeoye and Adeoye, 2017; Hsu *et al.*, 2019; Putri *et al.*, 2022; Yustina, 2022). It reported that the digital literacy skills of 367 students in Iran needed improvement. In contrast, Adeoye and Adeoye (2017) reported that almost 595 respondents in Nigeria expressed confidence in several digital literacy ability variables, such as adhering to the code of ethics for plagiarism and possessing information technology skills. Nilsook (2018) provided information indicating that 400 students in Thailand reached the medium category in information skills and the high category in using digital tools.

Research on digital literacy assessment in Indonesia has been conducted extensively since the onset of the Covid-19 pandemic (Putri *et al.*, 2022; Yasa *et al.*, 2024; Yustina, 2022). According to Putri's (2022) research, the following may be used to characterize the digital literacy abilities of 74 students from 7 universities. In terms of information and data literacy, most pupils are proficient at the foundation level. Furthermore, most pupils have proficiency in level 2 (intermediate) software and hardware operations. Nevertheless, in terms of digital literacy ability, none of the pupils possess level 3 (advanced) or level 4 (extremely advanced) skills. Yustina (2022) provided information on the digital literacy abilities of 120 high school students at the secondary education level. It was discovered that 56% of respondents believed they were unaware of the safety risks associated with digital technology, and 55% said they had never received instruction on how to consult official publications.

Additionally, 60% of respondents reported being less cautious when selecting material from the internet, and 50% stated that they needed help interacting and conversing digitally. Additionally, a sizable 70% of respondents said it was unnecessary to assess information obtained online. The survey's initial results improved after using digital media to enhance learning. Thus, it is imperative to aim for lectures integrated with digital media to enhance students' digital literacy, particularly at advanced and highly skilled levels. By providing students with exposure to digital technologies and real-world experience, this integration can improve their ability to locate and analyze information online.

One of the digital media that is widely used today is augmented reality. The involvement of augmented reality can affect cognitive aspects because it is an application designed to display images, animations, audio, and video files, as well as other interactive media, on real-world objects via smartphone devices (Naese *et al.*, 2019). Our previous work suggests the advantages of augmented reality and virtual reality for chemistry students' non-cognitive aspects, including interest, motivation, and attitude (Sari *et al.*, 2025). ICT-based media like this not only helps convey content but also helps students be more independent in learning (Habiddin *et al.*, 2022). Problems not only in the classroom but also in the chemistry laboratory have been successfully resolved by augmented reality (Plunkett, 2019; Tee *et al.*, 2018; Yang *et al.*, 2021). The use of augmented reality in conducting practical offers advantages, as it reduces the cost of carrying out practical and allows them to be done anywhere. Additionally, it enhances students' conceptual understanding of practical material while minimizing the use of chemicals and alleviates students' anxiety about the use of hazardous substances (Broyer *et al.*, 2021; Gungor *et al.*, 2022). The effectiveness of augmented reality media is not only limited to improving cognitive aspects but also plays a role in enhancing other pedagogical aspects (Amiati, 2019; Ardyansyah and Rahayu, 2023; Elford *et al.*, 2022; Gungor *et al.*, 2022; Penn and Ramnarain, 2019; Putra *et al.*, 2021; Rahmawati *et al.*, 2021; Yildirim, 2020). However, further research is still needed on the role of augmented reality in enhancing digital literacy skills, particularly in chemistry education (Hsu *et al.*, 2019; Yang *et al.*, 2023).

Some concepts in chemistry learning are difficult to understand (Parlan *et al.*, 2020). One of the most important concepts in chemistry learning is acid-base titration. An acid-base titration is a method in volumetric analysis where quantitative analysis is based on the amount or volume of a solution with a known concentration required to react completely with a component in a solution of unknown concentration (Christian, 2004). Acid-base titration involves mastering the concept of acid-base equilibrium as well as understanding the procedure of the titration itself. In general, mastery of chemistry concepts can be mastered through lectures that employ a scientific approach, focusing on problem-solving and incorporating observation to explain phenomena related to the results of observations (Muntholib *et al.*, 2020). Media with augmented reality will contribute to offering an observational simulation. Students will be able to practice observing acid-base titration settings with the aid of this media. Information gathered through interviews revealed that the acid-base titration practicum is currently being implemented through trial and error. Students who struggle to distinguish the colors of solutions tend to use chemicals excessively. A strong argument for creating learning integrated with augmented reality digital media is that, in addition, the results of the curriculum analysis show that students must apply logical, critical, systematic, and innovative thinking in the context of developing or implementing science and technology. Additionally, this encourages initiatives to improve digital literacy.

Hsu *et al.* (2019) reported that they measured the effectiveness of digital literacy using an instrument developed from a combination of the digital literacy framework by the Research Center European Commission. Their measurement of digital literacy focused on elementary school students and thus did not encompass other aspects that could be relevant for students at higher levels of education, particularly at the tertiary level (Payton, 2010; Yustina, 2022). To support the development of augmented reality media, it is crucial to test the effectiveness of digital literacy within various frameworks. This approach enables a detailed and targeted analysis of digital literacy skills. Therefore, the following research questions were answered in this study:

1) How are the validity and practicality of mobile augmented reality titration (MART)
2) How the effectiveness of MART on digital literacy skills enhancement

2. Experimental

2.1. Method

This research employs the Ploomp development model, which comprises three stages: the initial investigation stage (preliminary study), the development or prototyping phase, and the assessment stage (Ploomp, 2013). The preliminary research stage aims to gain an overview of the problems that occur and to find solutions to those problems. Activities carried out in this stage include problem and needs analysis, curriculum analysis, and concept analysis. The analysis of problems and needs is described based on interviews with 15 students from the Chemistry Education Department (Tadris Kimia), using indicators related to media characteristics, such as the accuracy of content, compatibility with technology and the environment, ease of understanding, and the need for media. Based on the interviews, it was concluded that acid-base titration lectures need to be conducted in the laboratory. However, to improve efficiency and minimize chemical waste disposal, a deeper conceptual understanding of titration materials is necessary so that students are better prepared before conducting practicum sessions. In addition, learning approaches are needed to support students' ability to interact with digital devices. This need arises from the growing awareness of the importance of these soft skills in adapting to the dynamics of the workplace after graduation.

In the context of curriculum analysis, this is based on one of the points from the Indonesian National Qualifications Framework (KKNI), which requires the application of logical, critical, systematic, and innovative thinking in the context of developing or implementing science and technology while considering and applying humanistic values in the field of chemistry. In this regard, the use of Augmented Reality applications is an example of technology integration in learning and simultaneously strengthens students' digital literacy skills.

Concept analysis was conducted to identify, elaborate, and systematically organize the concepts needed as a reference in developing chemistry learning media based on Augmented Reality. As a reference for analysis, the acid-base titration subject matter includes classification of acid-base titration methods, acid-base equilibrium, construction of acid-base titration curves, and implementation of acid-base titration. Based on the analysis of the subject matter, it is evident that acid-base titration material requires learning experiences that demonstrate the titration process. Augmented Reality technology is suitable for use in volumetric analysis lectures because it can display 3D images and practicum videos that help students understand the course material from anywhere.

In the development or prototyping phase, the design of a chemistry learning medium based on Augmented Reality is conducted. In the assessment stage, trials are conducted with research subjects to determine the practicality and effectiveness of the chemistry learning medium in improving digital literacy skills related to learning acid-base titration. The research stages in the Ploomp method are considered more flexible, especially in accommodating the evaluation phase of the prototype to be developed. This provides an advantage for this study, which requires the prototype to be validated in the early stages before further implementation. The detailed sequence of research activities is illustrated in Fig. 1. Several general criteria for obtaining high-quality interventions were also considered: validity and practicality. During the assessment phase, the effectiveness of the prototype in enhancing digital literacy skills is evaluated. The testing is conducted using a quasi-experimental design, specifically a non-equivalent posttest-only control group design. The research subjects were chemistry education students enrolled in the Basic Analytical Chemistry course at a university in Indonesia. The sample classes were selected using the convenience sampling technique.

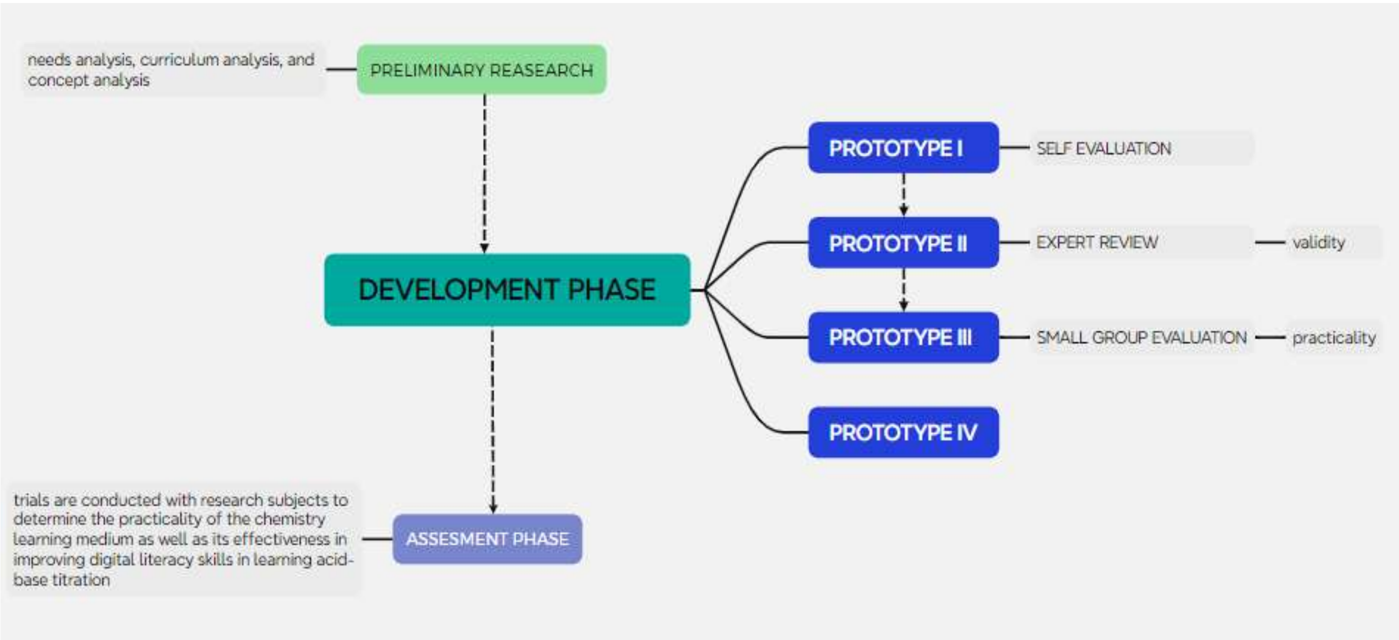

Figure 1. Stages of research activities based on the Plomp development model.
Source: Elaborated by the authors.

2.2. Procedure and participants

The initial stage of the research procedure involves conducting a preliminary investigation. This stage aims to provide an overview of the existing problems and identify solutions, which consist of problem and need analysis activities, curriculum analysis, and concept analysis. In the second stage, known as the prototype-making stage, a chemistry learning media based on Augmented Reality for acid-base titration material was designed. The primary application used to develop Augmented Reality technology is Unity 3D. The hardware necessary to run this augmented reality application is an Android smartphone or tablet with the following minimum specifications: Android OS 2.3.2 "Ginger Bread" (API Level 9), 75.62 MB RAM, and a 2 MP camera. The required software includes Unity 3D 2018, Vuforia SDK API 27, JDK 1.8, Java Development Kit, Visual Studio Community 2017, Blender, Corel Draw X7, and Star UML. The third stage includes a trial and assessment stage to evaluate the impact of the media on digital literacy skills. The research samples used for large-scale testing consisted of 60 chemistry students from a university in Indonesia (the university is assigned the code A), divided into control and experimental classes. A small-scale test was conducted with 20 students from the chemistry education study program at a university in Indonesia (the university is assigned the code B).

2.3. Data collection and analysis techniques

The data in this research comes from validity and practicality test questionnaires, as well as a digital literacy skills test questionnaire. Validity test data are obtained from the results of experts validating the learning media. The validators include four lecturers: two specializing in science education evaluation, one in chemistry, and one with expertise in IT. Validity data are collected from the outcomes of cross-checking instruments or products using validation tools, as reviewed by experts. The assessment is conducted by validators using a Likert scale: (1) Strongly Disagree; (2) Disagree; (3) Neither Agree nor Disagree; (4) Agree; (5) Strongly Agree. The data obtained were analyzed using **Eq. 1** (Sumadi *et al.*, 2022):

$$N = \frac{\Sigma X}{\Sigma maks} \times 100\% \quad (1)$$

Noted, N is the score; is the total score obtained; Σ max is the maximum number of scores. The calculation results will be interpreted using **Table 1**. The validity level was categorized according to the following criteria: 81-100 for excellent, 61-80 for high, 41-60 for moderately valid, 21-40 for low, and 0-20 for invalid. Practicality test data were obtained from the implementation of the MART trial on acid-base titration. The assessment was carried out by students using a response questionnaire: (3) Neither Agree nor Disagree; (4) Agree; (5) Strongly Agree. The data collected was analyzed using **Eq. 2** (Sumadi *et al.*, 2022). The calculation results were interpreted according to the following categories: 90-100% for very practical, 80-89% for practical, 65-79% for moderately practical, 55-64% for less practical, and <54% for not practical.

$$Practical\ Value = \frac{Score\ obtained}{Maximum\ score} \times 100\% \quad (2)$$

The digital literacy skills test data, collected using a questionnaire with 18 questions adapted from Payton's (2010) framework, are presented in **Table 1.** The assessment was only carried out on 5 of the 8 aspects developed by Payton (2010) due to the unsuitability of measuring the aspects of collaboration, cultural and social understanding, and e-safety. This discrepancy is caused by the nature of the media being developed, which does not support the implementation of interactions globally.

Table 1. Aspects of measuring digital literacy skills.

Aspect	Indicator
Functional Skills and Beyond	1. ICT capabilities in the Internet sector 2. Ability to operate augmented reality media
Creativity	1. Ability to create augmented reality media using digital technology 2. Creative thinking ability 3. Imaginative thinking ability
Communication	1. Ability to communicate via digital technology media 2. Ability to understand the audience while using virtual media
The ability to find and select information	1. Ability to search for information in digital space 2. Ability to select information in the digital space 3. Ability to contribute when dealing with information in the digital space
Critical Thinking and Evaluation	1. The ability to think critically when dealing with information in the digital space 2. Ability to analyze when dealing with information in the digital space

Source: Elaborated by the authors.

Inferential statistical analysis is used to determine the effectiveness of augmented reality media on digital literacy skills. In this research, inferential statistical analysis involves measuring the instrument's validity, which is assessed using the product-moment correlation. The normality test for data distribution is required to determine the type of statistics used in effectiveness analysis. Testing was conducted using the Shapiro-Wilk test, with a significance level of 0.05, via the IBM SPSS for Windows program. The homogeneity test determines whether the research data has a homogeneous variance. The homogeneity test was carried out using the Levene test at a significance level of 0.05 with the IBM SPSS for Windows program. The t-test is used to determine whether there are differences between treatments. Hypothesis testing using the t-test with a confidence level of 95% via the IBM SPSS for Windows application. The effect size test was conducted using Cohen's d with the criteria: <0.05 for small, 0.5-0.6 for medium, 0.7-0.9 for large, and ≥1 for very large.

3. Results and discussion

3.1. Development of mobile augmented reality titration (MART)

The media product developed is called MART, which provides a simulation of the acid-base titration process. This media is based on augmented reality and can be applied via smartphone or tablet. The results of the development can be seen in **Fig. 2**.

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Figure 2. The menu of MART.
Source: Elaborated by the authors.

Figure 2 displays the types of practicum. In the practical A menu, students can find a set of titration tools consisting of a burette, stand, burette clamp, and Erlenmeyer flask. Practical menu B is the implementation of strong acid and base titrations, while practicum C is the implementation of weak acid-base titrations. In Practical A, students can find a simulation of a strong acid (HCl) titrated by a strong base (NaOH). In Practical B, a simulation of a weak acid (acetic acid) titrated by a strong base (NaOH) can be found. Each titration in Practical A and B uses phenolphthalein as an indicator, causing the solution's color to change from clear to pink. **Figure 3** shows the equipment of a titration set, as viewed from the barcode display. In this menu, students can only observe the titration set but are unable to perform an acid-base titration simulation.

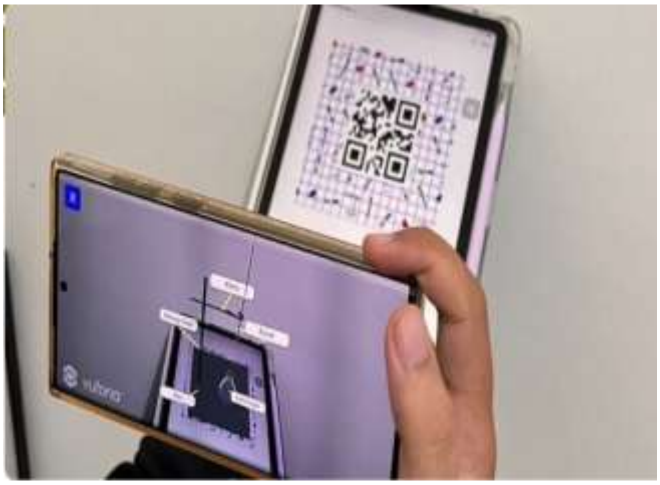

Figure 3. The display of distillation equipment's viewing from the barcode MART.
Source: Elaborated by the authors.

Figure 4 shows the details of the titration set. In **Fig. 4**, students can see the titration set in more detail, allowing them to redraw the apparatus in their respective workbooks.

Figure 5 displays the lab view of titrating a strong acid and a strong base. The strong acid used is hydrochloric acid (HCl), which acts as the analyte. The strong base used is sodium hydroxide (NaOH), which acts as the titrant. The screen will display the color change of the analyte from clear to deep pink. The color of the solution in the Erlenmeyer flask will continue to change as the titrant is gradually added during the simulation. Students can observe the pH changes along with the color changes and then determine the endpoint of the titration based on the color change of the analyte.

Figure 4. The detailed display of distillation equipment based on MART.
Source: Elaborated by the authors.

Figure 5. Acid-base titration on MART.
Source: Elaborated by the authors.

Figure 6 shows the display of the practicum on an Android device. This menu will allow learners to interact by using the menus that appear on the monitor. The screen will display the volume of NaOH that will be added to the Erlenmeyer. Each drop of NaOH will appear in volume according to the number of times the burette image is touched. **Figure 6** shows a simulation of the titration of a weak acid with a strong base. The weak acid used is acetic acid (CH_3COOH), which acts as the analyte, while the strong base used is sodium hydroxide (NaOH), which acts as the titrant. Like the practical in Menu A, students can observe changes in pH along with color changes.

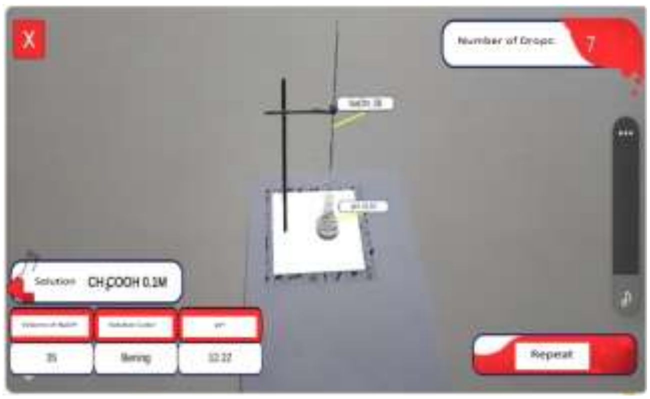

Figure 6. Implementation of Acid-Base Titration Practicum from an Android perspective.
Source: Elaborated by the authors.

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3.2 Mobile augmented reality titration (MART) assessment

The MART prototype was tested, and the validity of the product is demonstrated in **Table 2**. The table shows that the validity of developed MART falls into the “excellent” category. This assessment relies on the average evaluation of the four components by the validator. Indicators assessed by experts include content components, construct components (presentation), linguistic components, and graphic elements. This aligns with Purwanto's statement that a product is considered valid if it complies with its content and constructs (Purwanto, 2012). An evaluation technique is deemed to have high validity (also referred to as validity) if it accurately measures what it is intended to measure. Therefore, it can be concluded that the MART media already meets the validity criteria. The testing of the product’s practicality is presented in **Table 2**.

Table 2. Validation results of augmented reality for acid-base practicum.

No	Validation aspects	Score	max score	%	Validity level
1	Aspects of content components	77	84	91.7	Excellent
2	Aspects of Construct Components	20	24	83.3	Excellent
3	Aspects of Linguistic Components	54	60	90	Excellent
4	Graphic Component Aspects	44	48	91.7	Excellent

Source: Elaborated by the authors.

The practicality of the MART application was assessed by testing it on students in the basics of Analytical Chemistry course as preparation for the acid-base titration practical. Information obtained from the questionnaire assessment of students indicated that the products created were efficient, with an average score of 88.63% (**Table 3**). Practicality is closely linked to the usability of learning media used in the lecture process, demonstrating the ease of use and implementation of learning with the produced products. Considerations for practicality can be observed in aspects such as ease of use, the time required for implementation being brief, rapid, and precise, as well as the appeal of the media to student interest (Sukardi, 2012). Thus, MART has good potential in supporting practical activities of acid-base titration.

Table 3. Augmented reality practical test results for acid-base practicum.

No	Practicality aspect	Score	Max Score	%	Note
1	Ease of use	353	400	88.25	Very practical
2	Learning time efficiency	37	40	92.5	Very practical
3	The benefits and attractiveness of media on student interest	319	360	88.61	Very practical
Total		709	800	88.63	Very practical

Source: Elaborated by the authors.

3.3. Measuring the effectiveness of digital literacy

Measuring the effectiveness of digital literacy begins with assessing the validity of the instrument. Based on the results of statistical calculations, it can be observed that the calculated “r” value for each question item (P1, P2, etc.) is compared with the “r” table, which yields a value of 0.3610. Questions that do not fall into the valid category are then discarded. Prerequisite tests were conducted in both the control class and the experimental class. Normality testing was performed using the Shapiro-Wilk test via SPSS 25. Data interpretation was conducted using a significance level of $\alpha = 0.05$. Based on the test results, it can be concluded that the research data are normally distributed because the “sig” values for both the experimental class (0.684) and the control class (0.519) are less than or equal to $\alpha = 0.05$. Homogeneity testing was performed using the Levene test in SPSS 25. From the test results, it can be concluded that the research data is homogeneously distributed because the “sig” value is 0.171, which is less than or equal to $\alpha = 0.05$. Analysis of the increase in digital literacy skills can be examined in more detail in **Fig. 7**.

Figure 7 provides information about digital literacy skills from five aspects: functional skills and beyond, creativity, communication, the ability to find and select information, and critical thinking and evaluation. There appears to be a significant difference in functional skills and beyond literacy between the control and experimental classes. The experimental class scored 84, while the control class scored 44. This data demonstrates that the involvement of augmented reality media enhances digital literacy skills (Suwarto *et al.*, 2022). The impact of MART can be reinforced from interviews with students in the experimental class, as in the following excerpt,

> The MART media provides me with opportunities to be more exposed to digital media, so I am compelled to practice my skills in understanding how to use the media. This also encourages my analytical ability regarding the data that appears on MART.

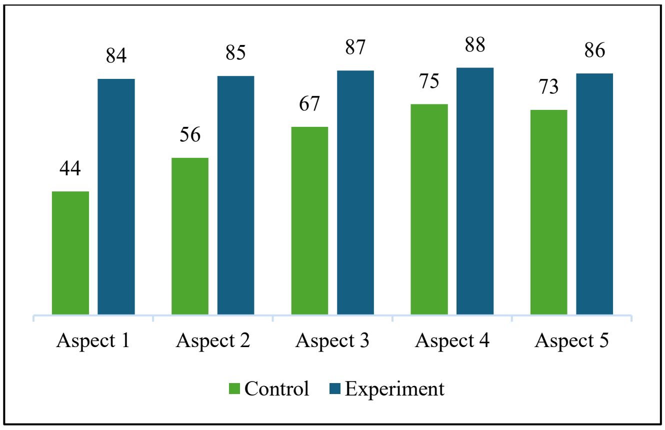

Figure 7. Students' digital literacy in using augmented reality media.
Source: Elaborated by the authors.

This interview excerpt is evidence that the MART media can accommodate the demand for introducing digital media as a basic skill that students must possess. The involvement of augmented reality in the functional skills and beyond aspect is also related to its role as an aspect of media literacy, which involves the ability to access, analyze, evaluate, and create media in various forms (Erdem *et al*., 2023; Martin and Grudziecki, 2006). Although media literacy skills were not directly measured, it is assumed that students already possess the basic knowledge. So, the role of media literacy becomes one contributor to improving functional skill aspects beyond the digital literacy component.

Creativity has increased in classes that were intervened with MART. The disparate assessment results between the experimental and control classes evidence this. The experimental class scored 85, whereas the control class scored 56. The effect of the MART media on this indicator can be investigated in the following interview excerpt with a student.

> I am able to think creatively after doing the acid-base titration simulation through the MART media. From YouTube videos, I could only imagine how the titration process is conducted, but by doing the simulation, I can better visualize the process. This really helps me prepare for the titration in the laboratory. I can even draw the titration apparatus in my workbook without referring back to the practical guidebook.

From the interview excerpt, it can be concluded that the use of MART media enables students to build their creativity while simultaneously enhancing their understanding of the titration process in the laboratory. Constructivist activities conducted through digital technology often hold the promise of fostering creativity and skills (Alt and Raichel, 2020). However, creativity in the context of digital literacy will not be achieved if it is not driven by learning objectives based on pedagogical aspects (De-Marcos *et al*., 2014). This confirms that MART, validated by the pedagogical component, has a better influence on student creativity than other students.

The communication aspect in the experimental class received a score of 87, while in the control class, the score was 67. Being exposed to digital media for a longer period in the experimental class is a logical reason for the high score in this class, as it enables students to communicate digitally more effectively than those in other classes (Yustina, 2022). The improvement in the communication indicator can also be seen in the following interview excerpt:

> Understanding the titration process through YouTube videos does not provide direct interaction for me, but the simulation conducted through MART media stimulates me to connect with the instructions given by the teacher regarding the type of observations I need to make. At the same time, I am encouraged to communicate with my teammates about how the simulation is carried out until I can obtain data that I then use to construct a titration curve.

It can be concluded that the MART media can create a better connection with the titration procedure while also encouraging students to communicate what has been simulated. The communication process through this media is certainly more effective compared to simply asking students to watch a one-way video. Indicators of communication skills can be observed in their understanding of the instructions provided through MART. Another visible indicator is the desire to share ideas in the context of digital media, which often follows the successful development of their understanding. Although no research has been found that explains in detail how communication aspects influence digital literacy skills as a whole, based on Payton's (2010) definition, the indicators shown in the research have strengthened the notion that enhancing comprehensive digital literacy skills is also influenced by students' communication skills.

The experimental class scored 88 in terms of the ability to find and select information, while the control class scored 75. The scores obtained in the two classes did not differ significantly, indicating that both classes possessed the basic ability to analyze information through digital media, which suggests that students already have this skill. The impact of the MART media on this indicator can be seen in the following interview excerpt;

> I was encouraged to independently find information about the pH at the endpoint of the titration through the MART media. Based on the simulation, I observed the exact color change, indicating the titration endpoint, and monitored the pH changes during the process. This allowed me to perform a mathematical analysis to compare the data obtained from the MART media simulation. It helped me better understand how the titration process works in determining the concentration of an unknown solution.

However, these abilities were trained more effectively in the experimental class than in the control class. Similar findings were also reported in Yustina's (2022) research, which explored the use of digital interactive media in enhancing digital literacy.

The critical thinking and evaluation aspect in the experimental class received a score of 86, while in the control class, it was 73. Based on observations, students in the experimental class were able to analyze the information contained in MART and then apply it to solve questions related to that information. The impact of this indicator can be seen in the following interview excerpt:

> I became more critical of the MART media titration simulation because I felt challenged to recalculate, through mathematical analysis, the pH of the analyte solution after the addition of a certain volume of titrant. This challenge trained me to perform mathematical analysis to determine the concentration of the analyte solution.

These results prove the influence of digital media on students' critical thinking and evaluation skills. Digital classrooms often require students to process information from various sources accurately and then critically evaluate and assimilate it to construct knowledge. Critical thinking and evaluation skills can be developed by creating a digital environment.

Thus, **Fig. 7** provides a comprehensive picture of the influence of MART on digital literacy skills. The results of the independent t-test strengthen this assessment. According to the statistical testing results, the significance value (sig) is 0.000. When compared with the value of $\alpha = 0.05$, it can be concluded that the two classes are significantly different. The next test was conducted using Cohen's d formula to determine the magnitude of the treatment's influence, specifically the use of mobile augmented reality titration, on the experimental class. The value of $d = 3.85$ was obtained in the calculation results. Interpretation is conducted through the effect size categories in **Table 4**, leading to the conclusion that MART has an incredibly significant influence on digital literacy skills. This also corroborates previous research that elucidates the relationship between the use of augmented reality and digital literacy skills (Hsu *et al*., 2019). In line with Hsu *et al*. (2019), students' authentic experiences with contextual and interactive augmented reality contribute to the development of digital literacy skills. This can be observed from the assignments given through augmented reality media, which require: (a) efforts to solve technical problems related to the use of augmented reality so that it can display the required information; (b) the ability to think imaginatively from the augmented reality animated visual display to adapt it to the real environment; (c) communication and collaboration both online and offline to construct conceptual understanding from information obtained in augmented reality; (d) critical thinking and the ability to evaluate the displayed data; (e) providing an understanding of social phenomena, especially in the aspect of digitalization.

Table 4. Effect size categories.

Range	Criteria
<0.05	Small
0.5 – 0.6	Medium
0.7 – 0.9	Large
≥1	Very large

Source: Elaborated by the authors.

Although augmented reality empirically improves digital literacy skills, its implementation in digital-based learning poses a challenge due to its close relationship with pedagogical competencies, which also change with the involvement of digital media (McGuinness and Fulton, 2019). Therefore, several studies report on combining digital media with effective learning models, such as blended learning or project-based learning, to optimally support the enhancement of digital literacy competence (Yang *et al.*, 2023).

4. Conclusions

The developed mobile augmented reality titration (MART) is a highly valid and practical product. MART can also have a considerable influence on students' digital literacy skills. The improvement in digital literacy can be seen from the increase in the average indicators between the experimental class and the control class, as detailed below: functional skill and beyond increased by 47%, creativity by 34%, communication by 22%, the ability to find and select information by 14%, and critical thinking and evaluation by 15%. The use of technology should not be limited to content. It is crucial to present problematic situations that give meaning to the content being taught. Therefore, adopting approaches such as problem-solving, case studies, or problem-based learning is recommended for future research. This research also has areas for improvement, including the small number of samples used and the lack of pedagogical elements in the learning process, which should be addressed by applying learning models. Therefore, it is necessary to consider integrating digital media into an effective learning model to achieve maximum results. Basic data regarding the influence of digital media integration in the learning process can be used as research implications to enhance students' digital literacy skills, thereby fostering innovation and further development of digital media that supports learning.

Authors' contribution

Conceptualization: Maya Sari; Muntholib Muntholib; **Data curation**: Maya Sari; Habiddin Habiddin; **Formal Analysis**: Maya Sari; Sumari Sumari; **Funding**: Not applicable; **Investigation**: Maya Sari; Muntholib Muntholib; **Methodology**: Maya Sari; Muntholib Muntholib; Habiddin Habiddin; **Project administration**: Sumari Sumari; **Resources**: Habiddin Habiddin; Sumari Sumari**; Software**: Not applicable; **Supervision**: Muntholib Muntholib; **Validation**: Habiddin Habiddin; Sumari Sumari; **Visualization**: Maya Sari; **Writing–original draft**: Maya Sari; Muntholib Muntholib; **Writing –review & editing**: Maya Sari; Muntholib Muntholib; Habiddin Habiddin**.**

Conflict of interest

The authors declare that there is no conflict of interest.

Data availability statement

All data sets were generated or analyzed in the current study.

Artificial Intelligence usage statement

The authors declare that they did not use Artificial Intelligence tools at any stage of the preparation, correction, or evaluation of this work.

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