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Development of a mobile learning network for science with augmented reality and its impact on students' literacy and numeracy

Ucu Cahyana[1], Ika Lestari[2], Irwanto Irwanto[3*], JarotSembodo Suroso[4]

[1,3]Department of Chemistry Education, Universitas Negeri Jakarta, Jakarta 13220, Indonesia.
[2]Universitas Negeri Jakarta, Jakarta 13220, Indonesia.
[4]Information Systems Management Department, Bina Nusantara University, Jakarta11480, Indonesia.

Corresponding Author: Irwanto Irwanto (*Email: irwanto@unj.ac.id*)

Abstract

The aim of the current research is to develop the Mobile Learning Network for Science application with Augmented Reality (MLNFS-AR) application on the topic of atomic structure and chemical equilibrium. The study was conducted in four public schools in Jakarta, Indonesia. The Borg and Gall development cycle was adopted in this study, including preliminary research, planning and developing learning media, and validation, evaluation, and revision. Regarding the assessment results from media experts, the mobile learning application was declared very feasible with a percentage of 91.7% for the topic of atomic structure and 87.2% for the topic of chemical equilibrium. The results of the material and language feasibility assessments were 81.6% for the topic of atomic structure and 82.3% for the topic of chemical equilibrium. The results of the media assessments for students were 92.9% for the topic of atomic structure and 89.9% for the topic of chemical equilibrium. The results of the media assessment by chemistry teachers were 97.1% for the topic of atomic structure and 94.7% for the topic of chemical equilibrium. Overall, this mobile learning medium is categorized as very feasible to use as a learning support medium. In addition, the MLNFS-AR app is effective in improving student literacy and numeracy. In sum, the mobile learning app, MLNFS-AR, can be used as a flexible learning medium, can be used anytime and anywhere, and makes it easier for students to learn chemistry.

Keywords: Atomic structure, Augmented reality, Chemical equilibrium, Literacy, Mobile learning, Numeracy.

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1. Introduction

Mobile learning (m-learning) is an alternative learning model that adopts the development of mobile technology and smartphone devices that have characteristics that are independent of place and time. Historically, m-learning first appeared in the 1970s and 1980s [1]. According to Saphira [2], the trend of m-learning has increased in the last eleven years, with 1906 publications about m-learning from 2010 to 2021. This indicates that m-learning is in demand and has the potential to be developed as an alternative learning medium.

Widiyaningsih, et al. [3] suggest that chemistry can be represented at three levels known as the "chemistry triplet," namely that chemistry includes three representations. The three representations are macroscopic, submicroscopic, and symbolic. Chemistry is one of the subjects that are difficult to understand because it requires the ability to connect the three representations of chemistry learning. Chittleborough and Treagust [4] suggest that some students have difficulty learning chemistry because they are unable to visualize structures and processes at the submicroscopic level and relate them to other levels.

In the process of learning atomic structure in class, there are still problems that occur because the material contains many macroscopic, submicroscopic, and symbolic concepts that are not easy for students to understand because they involve chemical reactions and chemical calculations and consist of concepts that are chemical in nature, abstract, and considered by students as material that is relatively new and has never been obtained at previous levels of education[5]. According to Prayunisa and Mahariyanti [6], the difficulties experienced by students in learning chemistry are in understanding chemical concepts; students easily give up and despair in solving chemistry problems, and students are unable to formulate and carry out solving strategies. This is in line with the results of existing research that: i) students often experience misconceptions in learning chemistry [6-9]; ii) abstract chemical concepts [6, 10]; and iii) chemistry learning is still teacher-centered so that students are passive and their abilities do not develop [6, 11, 12].

In addition, Adaminata and Marsih [13] stated that chemical equilibrium material is an abstract concept, and the majority of students have difficulty understanding the dynamic nature of equilibrium reactions. Meanwhile, according to Dewi [14], in general, these chemical reactions take place in alternating directions (reversible), and only a small number of them take place in one direction. When the reaction rates toward the products and toward the reactants are the same and the concentrations of the reactants and products do not change, a dynamic equilibrium is reached. Under certain conditions, the concentrations of reactants and products remain constant. Such reactions are called reversible reactions which reach equilibrium.

M-learning integrated with augmented reality (AR) technology can be utilized as an alternative medium to overcome these problems. M-learning integrated AR is a learning medium in the form of an android-based mobile application that integrates augmented reality into it as a learning medium that can be used by teachers to teach in class. AR is a technology for visualizing learning through 2D or 3D modeling from the virtual world to the real world in real time. In use, AR can be applied via computers or smartphones equipped with camera devices; in this case, AR can be integrated into m-learning.

Previous research that developed and used AR-integrated m-learning was carried out by Abdinejad, et al. [15]. The research aims to create comprehensive, inexpensive, flexible, and easy-to-use educational content to make it easier for students to understand molecular structures and their 3D spatial abilities and measure students' perceptions of 3D molecular structure and visualization using the tools developed (integrated mobile learning augmented reality) named ARchemy. The results showed positive feedback regarding the effectiveness of ARchemy technology in increasing students' understanding of complex chemical concepts. According to student feedback, this technology (ARchemy) can assist students in understanding chemistry better than traditional modeling methods [15]. Similar research was also conducted by Li and Liu [16];Sungkur, et al. [17];Radosavljevic, et al. [18] and Chiang, et al. [19].

The needs analysis questionnaire that the researcher distributed to tenth-grade students at a public high school in Jakarta provided information that 57.3% of students out of a total of 96 student respondents stated difficulties in understanding atomic structure material. One of the difficulties found in atomic structure is abstract concepts or theories, such as understanding the composition of atomic structure, so it is necessary to create visualizations that can help students understand atomic structure material. The results of the needs analysis also provide valuable information about the desired features in m-learning media, namely a guide to using m-learning (92.7%), practice questions (quizzes) (91.7%), learning videos (92.7%), discussion forums (90.6%), and augmented reality (88.5%).

The use of appropriate learning media can be considered one of the main factors influencing student learning outcomes. In the existing literature, learning media is conceptualized as everything that is utilized in the learning environment in order to increase students' knowledge, promote positive attitudes, and develop their skills [20]. In addition, the use of interactive learning media in the classroom can foster students' interest and desire to learn, increase engagement and motivation, and enhance student enjoyment. Based on an analysis of the needs of grade 11 students at another public high school in Jakarta regarding learning chemical equilibrium, it was found that 90% of students stated that the teacher explained via PowerPoint with the help of Quizzes or Kahoot by 45%. Also, the results of the analysis of the needs of teachers regarding the difficulties encountered when delivering chemical equilibrium material show that 100% of optimal media is not yet available.

According to the aforementioned issues, researchers are encouraged to develop m-learning apps integrated with AR on the topic of atomic structure and chemical equilibrium. Accordingly, the development of m-learning media integrated with AR is expected to become an innovative learning medium for studying and understanding chemical material, especially atomic structure, by connecting the material to students themselves, which aims to familiarize students with constructing students' critical thinking skills in discovering knowledge independently.

2. Literature Review

2.1. Augmented Reality (AR)

Theoretically, AR is considered a new technology for mixing virtual and real information that allows students to experience feelings as they do in everyday life. In short, because AR provides near-real-world operations, students can interact with virtual 3D objects in a real-world context [21]. Since AR allows students to directly experience the real world coupled with virtual objects, this learning environment can foster students' curiosity, which in turn can influence their attitudes and behavior towards learning chemistry [22]. Interestingly, AR-assisted learning activities not only provide learning flexibility for students but also promote their motivation to learn [21]. Considering the various advantages of this new technology, educators and researchers are advised to take advantage of AR technology to support chemistry learning. Therefore, in the present study, we designed and developed a Mobile Learning Network for Science supported by AR technology (MLNFS-AR) to improve students' 21st-century competencies, namely literacy and numeracy.

2.2. Literacy and Numeracy

In literature, literacy refers to a person's skills that can be trained and enhanced [23]. The term literacy refers to a concept related to students' perceptions of life, including understanding objects and events in their lives and interpreting their relationships in social life [23]. Thus, higher levels of literacy are often associated with students' ability to respond to and resolve issues related to science and technology [24]. Considering the low level of student literacy, which is a concern throughout the world, it is important to improve literacy. This is because literacy is an important part of understanding the world and making the right decisions [25]. In addition, numeracy is postulated as the "skills students need to understand about the role of mathematics in the world and apply mathematical knowledge and skills in their personal, social, and work circumstances that are constructive and meaningful" [26]. In other words, numeracy is related to the use of mathematical skills to improve an individual's life. Low literacy and numeracy skills impact access to well-paid jobs and more desirable opportunities [27]. Therefore, improving literacy and numeracy skills is an important key to developing students' reading and mathematics skills in the future [28]. More broadly, previous studies agree that literacy and numeracy play a role in enlightening citizens, reducing the cycle of poverty, and increasing a person's ability to participate in society [29].

3. Materials and Methods

3.1. Research Design

In this study, the research method used was Research and Development (RnD) with the Borg and Gall development model, which was simplified into three main stages, including the preliminary research stage, the planning and product development stage, as well as the product validation, evaluation, and revision stages Sugiyono [30]; Sukmadinata [31] and Wulandari, et al. [32]. Sugiyono [30] claimed that educational researchers frequently used the RnD method to create instructional content and evaluate its efficacy. Therefore, RnD can be said to be a method for producing a product that is useful for passing learning in the classroom. A m-learning app with AR support on the subject of atomic structure and chemical equilibrium was the end product of this study's development research. To determine the effectiveness of m-learning on student literacy and numeracy, we used an experimental design with a post-test design only. In this setting, a m-learning app was used in the experimental group, and the lecture method was used in the comparison group. After treatment, the literacy and numeracy tests were given to the control and intervention groups.

3.2. Participants

In this study, the mobile app was tested on 217 high school students and assessed for its feasibility by 12 experts and 8 chemistry teachers in Jakarta, Indonesia. The research was carried out from January to May 2023. In the implementation phase, we recruited 118 high school students and assigned them to control (n=56) and experimental (n=62) groups.

3.3. Instruments

3.3.1. The Instrument for Evaluating Design and Efficiency of Mobile Learning

This instrument was given to three experts to evaluate the Design and Efficiency Aspects of the mobile learning application. This instrument included 2 indicators and 18 items with a four-point Likert scale (from 4 "strongly agree" to 1 "strongly disagree"). The indicators consisted of the display of mobile learning media (e.g., "writing can be read clearly", "images can be seen well") and Software engineering and implementation (e.g., "visualization of augmented reality is clearly visible", "buttons on easy application to operate").

3.3.2. The Instrument for Evaluating Mobile Learning Content and Language

This instrument was given to three experts to evaluate the content and language aspects of the mobile learning application. This instrument consists of 3 indicators and 16 items on a four-point Likert scale (4 strongly agree and 1 strongly disagree). Indicators included the feasibility of mobile learning content (e.g., "Content in the application matches the learning objectives"), the presentation of mobile learning (e.g., "Illustrations are presented in accordance with facts to improve student understanding"), and the use of language in mobile learning (e.g., "Sentences and the language used are simple and easy to understand").

3.3.3. The Instrument for Evaluating the Quality of Mobile Learning

This instrument was given to students and teachers to evaluate the quality of mobile learning applications. This instrument included 6 indicators and 34 items on a 4-point Likert scale (4 strongly agree and 1 strongly disagree).

Indicators include content adequacy (e.g., "Material and questions are clear and correct"), feasibility of presentation (e.g., "Illustrations are presented according to facts to increase student understanding"), language appropriateness (e.g., "Sentences and language used are simple and easy to understood"), Visual appearance and video (e.g., "Neat and orderly layout"), software engineering and implementation (e.g., "Visualization of augmented reality looks clear"), and usefulness (e.g., "Learning by using the application is more interesting and fun").

3.3.4. The Literacy and Numeracy Test

To collect data, the researchers developed a test to assess students' literacy and numeracy in school chemistry subjects. The test included 15 multiple-choice items. Each question was given a score between 1 for a correct answer and 0 for an incorrect answer. The minimum score a student could obtain was 0, and the maximum was 15. After being validated by senior lecturers and chemistry teachers, Cronbach's alpha value was 0.78. This indicates that the test was reliable. Students were given approximately 90 minutes to complete the test.

3.4. Data Analysis

The results of the data were then obtained through validation questionnaires for media experts, material and language experts, chemistry teachers, and high school students. The data gathered were analyzed by calculating a Likert scale with a choice of 4 points. Based on various aspects that have been validated on a scale of 1 to 4, the data is analyzed descriptively with the following formula see Equation 1:

$$P_s = \frac{n}{N} \times 100\% \qquad (1)$$

Note:
Ps = Percentage.
n = Total score obtained from the assessment results.
N = Maximum score.
The results of the questionnaire were then analyzed with the following interpretations see Table 1.

Table 1.
Interpretation of assessment results.

Percentage (%)	**Interpretation**
< 20	Very poor (VP)
20.1 – 40.0	Poor (P)
40.1 – 60.0	Acceptable (A)
60.1 – 80.0	Good (G)
> 80.0	Very good (VG)

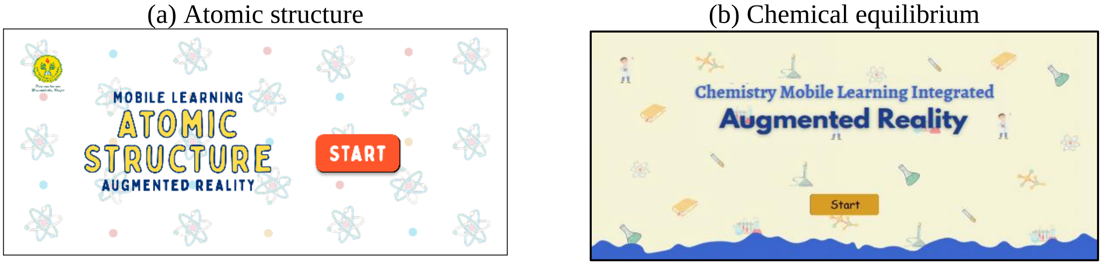
Statistical Package for Social Sciences (SPSS) 25.0 was performed for statistical analysis. The results are presented as the mean ± standard deviation (SD). In order to check whether the variables were normally distributed, the Kolmogorov-Smirnov test was performed. Because the normality of the data was not violated, we then analyzed the data with parametric tools, namely the independent sample *t*-test, to evaluate the difference in mean scores between the comparison and intervention groups. It should be noted that the significance level used was $p<0.05$.

4. Result and Discussion

The developed MLNFS-AR apps on the topics of Atomic Structure and Chemical Equilibrium as seen in Figure 1, have a resolution of 2340 x 1080 pixels, according to the size of a smartphone screen in general. The mobile learning media developed is in the form of an application in the.apk file format (Android package) version 1.0, which can be run on smartphones running Android operating system (OS) version 6.0 and above.

(a) Atomic structure (b) Chemical equilibrium

Homepage



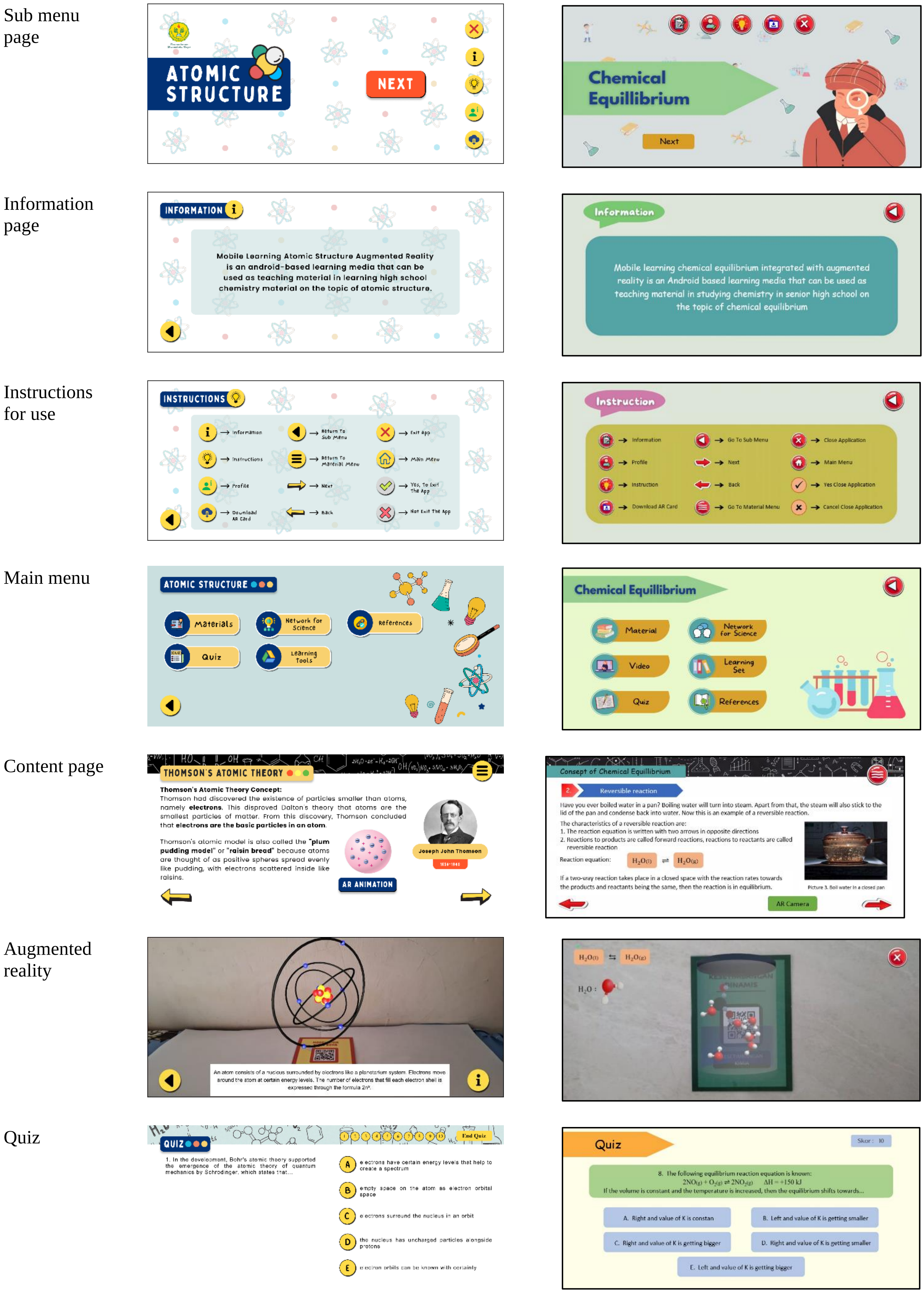


Figure 1.
Display of MLNFS-AR app on the topic of (a) atomic structure and (b) chemical equilibrium.

4.1. Results of Evaluation of Design and Efficiency Aspects of MLNFS-AR

The media expert's assessment covers two components, namely the appearance of the media and the implementation of software engineering. The instrument contains 18 questions to assess media performance and software engineering feasibility. The results are listed in Table 2.

Table 2.
Assessment results from media experts.

No	Aspect	Percentage	Criteria
Atomic structure			
1	Display of mobile learning media	88.5	VG
2	Execution and software engineering	95.0	VG
Average		91.7	VG
Chemical equilibrium			
1	Visuals and audio	86.5	VG
2	Augmented reality quality	87.5	VG
3	Execution and software engineering	87.5	VG
Average		87.2	VG

Note: VG = Very good.

The evaluation's findings for atomic structure indicate that software engineering, execution, and mobile learning app display all received scores higher than 80%. In addition, for chemical equilibrium, the assessment results indicated that visuals and audio, augmented reality quality, execution and software engineering also scored above 80%. This means that the mobile learning application belongs to the "Very Good" criteria.

4.2. Results of Evaluation of Content and Language Aspects of MLNFS-AR

The assessment of content and language experts includes three aspects, namely the appropriateness of content and presentation in the media and the suitability of language in the media. The results can be seen in Table 3.

Table 3.
Assessment results from content and language experts.

No	Aspect	Percentage	Criteria
Atomic structure			
1	Adequacy of content in the media	85.0	VG
2	Feasibility of presentation in the media	83.3	VG
3	Language suitability in the media	76.4	G
Average		81.6	VG
Chemical equilibrium			
1	Adequacy of content in the media	81.9	VG
2	Feasibility of presentation in the media	83.3	VG
3	Language suitability in the media	80.6	VG
4	Scientific approach	83.3	VG
Average		82.3	VG

Note: G = Good; VG = Very good.

Based on Table 3, all aspects of both atomic structure and chemical equilibrium score above 80%, except for language suitability in the media aspect of atomic structure, which scores 76.4%. It can be inferred that the MLNFS-AR application belongs to the "Very Good" criteria.

4.3. Results of MLNFS-AR Quality Evaluation

Mobile learning was evaluated by 217 high school students was assessed for its feasibility by 12 experts and 8 chemistry teachers. Researchers notify and provide links to download and install mobile learning applications to students and teachers directly via WhatsApp. After the application was successfully downloaded and installed, the researcher explained several mobile learning features and how to use them. In addition, the researcher gave students and teachers time to explore the application. Students and teachers are then given a large-scale media test questionnaire link to provide an assessment of the mobile learning that has been developed. Filling is done via Google Forms. The questionnaire for students consisted of 34 questions, which included six aspects of assessment: content feasibility in media, presentation feasibility in media, language suitability in media, visual and video appearance in media, software engineering implementation, and usability. The results are presented in Table 4.

Table 4.
Results of mobile learning evaluation by students.

No	Aspect	Percentage	Criteria
Atomic structure			
1	Adequacy of content in the media	93.3	VG
2	Feasibility of presentation in the media	92.0	VG
3	Language suitability in the media	91.8	VG
4	Visual and video displays on media	93.5	VG
5	Execution and software engineering	93.4	VG
6	Usefulness	93.6	VG
Average		92.9	VG
Chemical equilibrium			
1	Content eligibility	86.6	VG
2	Presentation eligibility	86.5	VG
3	Language suitability	87.7	VG
4	Visuals and audio	91.1	VG
5	Augmented reality quality	92.7	VG
6	Execution and software engineering	94.9	VG
Average		89.9	VG

Note: VG = Very good.

For atomic structure, the average percentage of eligibility for mobile learning is 92.9% with the "Very Good" criteria. Similarly, for chemical equilibrium, the average percentage of eligibility for mobile learning is 89.9% with the "Very Good" criteria.

Table 5.
Results of mobile learning evaluation by teachers.

No	Aspect	Percentage	Criteria
Atomic structure			
1	Adequacy of content in the media	95.8	VG
2	Feasibility of presentation in the media	95.0	VG
3	Language suitability in the media	97.5	VG
4	Visual and video displays on media	96.5	VG
5	Execution and software engineering	100.0	VG
6	Usefulness	97.5	VG
Average		97.1	VG
Chemical equilibrium			
1	Content eligibility	85.4	VG
2	Presentation eligibility	92.5	VG
3	Language suitability	100	VG
4	Visuals and audio	96.9	VG
5	Augmented reality quality	95.8	VG
6	Execution and software engineering	97.5	VG
Average		94.7	VG

Note: VG = Very good.

For atomic structure, the average percentage of eligibility for mobile learning is 97.1% with the "Very Good" criteria. Similarly, for chemical equilibrium, the average percentage of eligibility for mobile learning is 94.7% with the "Very Good" criteria see Table 5.

4.4. Effect of MLNFS-AR on Students' Literacy and Numeracy

After developing the MLNFS-AR application, we then implemented it in classrooms involving 118 high school students in the Lombok and Yogyakarta areas of Indonesia. The results are presented in Table 6.

Table 6.
The mean scores of the control and intervention groups.

Area	Group	N	Mean	SD	t	Df	Sig.
Lombok(*n*=44)	Experimental	22	7.227	1.109	2.703	42	0.010
	Control	22	6.091	1.630			
Yogyakarta(*n*=74)	Experimental	40	11.350	1.577	3.403	72	0.001
	Control	34	10.147	1.438			

Based on Table 6, a significant gap existed in mean scores between the intervention group using MLNFS-AR and the comparison group using the lecture method. In both Yogyakarta and Lombok areas, students in the intervention group outperformed students in the comparison group. This indicates that the use of MLNFS-AR is effective in promoting the chemical literacy and numeracy of high school students.

5. Discussion

The results of the present study are a m-learning app that is integrated with AR on the Android operating system. This research was conducted according to the Borg and Gall [33] development model, which comprised ten stages that were further simplified into three main stages, namely preliminary research, product planning and development, as well as product validation, evaluation, and revision [30-32]. The preliminary research stage is to conduct a needs analysis to identify problems with the needs and limitations of students and teachers in learning atomic structure material. In order to determine what is needed to create m-learning products that are integrated with augmented reality, the researcher at this point gave needs analysis questionnaires to chemistry professors and students. Based on the results of the needs analysis that has been obtained, it is important to develop a mobile app that is integrated with AR on atomic structure and chemical equilibrium. This is reinforced by Klimova [34] who says that m-learning has proven effective in increasing student achievement and contributing to positive learning outcomes. To support learning anywhere and anytime, Cahyana, et al. [35] also argue that m-learning apps can be used as learning media inside and outside the classroom.

The developed m-learning media is also integrated with AR, which can reach understanding at the submicroscopic level. The presence of 3D animation in AR can bridge students' understanding at three levels of representation. This is consistent with Cai, et al. [36] which suggests that the use of AR as a learning medium can reach something that cannot be observed with the naked eye, which is a representation of the submicroscopic level. From the results of this study, several comments were obtained that m-learning applications can run well and really help students learn atomic structure and chemical equilibrium. Chemistry becomes easier to understand and makes students more confident to take exams. In addition, m-learning is very useful for student learning anytime, anywhere, and with AR, it makes students more enthusiastic and happy to learn chemistry again. The results are in accordance with research byCahyana, et al. [37], who reported that m-learning apps can motivate students to study chemistry because they provide an interesting, attractive learning environment; thus, learning becomes more meaningful.

M-learning (m-learning) is a new way of using mobile and wireless technology for learning and educational purposes. In m-learning settings, students can combine their learning experiences in a collaborative environment [38]. Because it supports learning anytime and anywhere, m-learning has the potential to increase students' productivity and enable them to participate in learning activities without the limitations of place and time [39]. In previous studies, Cook [40] and Tianyu, et al. [41] revealed that the use of mobile devices and AR technology allows students to connect real-world and virtual information. Additionally, Kesim and Ozarslan [42] found that AR can be applied for learning and entertainment purposes.

In secondary education, one of the important goals is to promote literacy and numeracy skills among students. The use of mobile devices is believed to be a tool to improve literacy and numeracy. Students who are more engaged in literacy have better mental well-being [43]. Thus, teachers need to introduce AR technology to students. For example, Picton [44] surveyed 219 teachers and found that more than three-quarters felt that technology should be available to students to support students' literacy development. In other words, m-learning should be used to improve students' literacy and numeracy, offer personalized learning experiences, and as a way to gain authentic experiences [45].

AR is an effective idea for teaching content, increasing literacy, and improving students' skills [46, 47]. Previous studies [48] revealed that AR provides creative and valuable opportunities in education [48]. Furthermore, AR technology also supports increasing students' creativity and visualization thinking [49]. The increase in student literacy in this study may be because AR can make it easier for students to visualize chemical phenomena, understand complex concepts, and visualize abstract concepts. Thus, this learning medium can support student learning and improve their literacy [50]. AR technology has great potential for use in education. AR provides opportunities for students to engage in authentic learning and improve literacy and numeracy [51].

In the current study, the researchers found that students' literacy and numeracy can be improved using the MLNFS-AR app. Our findings are in line with earlier works [52-54]. The use of AR-assisted mobile technology to support literacy and numeracy programs is based on the fact that students use mobile devices every day to access information. Another reason is that students are very interested in interactive learning media such as AR applications, which make it easier for them to visualize the shapes of the particles that make up atoms and atomic models, which are actually microscopic in size, more easily and more pleasantly. AR technology is seen as making learning more meaningful [55] and increasing students' interest in studying chemistry. Additionally, the findings may be related to the fact that MLNFS-AR combines the virtual object with real-world environments to provide easy-to-understand and more realistic information. In turn, information that is easy for students to understand plays a crucial role in enhancing students' literacy and numeracy in the current study.

The use of mobile apps to promote student literacy and numeracy in an educational context has been documented. Earlier research also mentioned that m-learning was proven to increase students' literacy and numeracy [56], increase learning motivation [57], and improve concept understanding [58]. Similarly, Adelore and Akintolu [59] found that students who learned using mobile technology had higher achievement. Similarly, Leu, et al. [60] showed that reading abilities of students improved through web-based literacy activities. Thus, the use of digital applications is considered a promising tool for improving the literacy and numeracy of students [61]. In short, by using appropriate mobile devices [62], students can read and understand the lesson content thoroughly [63].

6. Conclusion

The product developed is a m-learning application with AR. This m-learning medium contains material, discussion forums, quizzes, AR, learning videos, a bibliography, and learning tools. According to the assessment of media experts, the m-learning application was declared very feasible with a percentage of 91.7% for the topic of atomic structure and 87.2% for the topic of chemical equilibrium. The results of the material and language feasibility assessments were 81.6% for the topic of atomic structure and 82.3% for the topic of chemical equilibrium. The results of the media assessment for students were 92.9% for the topic of atomic structure and 89.9% for the topic of chemical equilibrium. The results of the media assessment by chemistry teachers were 97.1% for the topic of atomic structure and 94.7% for the topic of chemical equilibrium. Overall, this m-learning medium produces a feasibility assessment with very feasible criteria. The results of implementation show that the MLNFS-AR is effective in elevating the literacy and numeracy of students. It is noteworthy that m-learning can be adopted as a flexible learning medium, can be used anytime and anywhere, and makes it easier for students to visualize models of atoms and the particles that make up atoms.

7. Implications

In this study, the effect of MLNFS-AR on students' literacy and numeracy was tested. The research results emphasized that there were significant gaps in literacy and numeracy scores between the group that used MLNFS-AR (experimental class) and the group that did not use MLNFS-AR (control class). The intervention group that used MLNFS-AR as a learning medium in chemistry subjects achieved better post-test results than the control group. This reflects that MLNFS-AR has a significant effect on secondary school students' literacy and numeracy. In this case, it can be said that students' literacy and numeracy skills can be improved through the use of new technology that combines virtual and real objects in an MLNFS-AR-based learning environment.

Students can use m-learning media as supporting media or alternative learning media to study chemistry, which is flexible and can be used anytime and anywhere. The resulting m-learning media is integrated with AR to make it easier for students to visualize models of atoms and the particles that make up atoms. So that chemistry can be well understood by students. In m-learning, there are also learning materials, discussion forums, quizzes, and other means that can provide new and interesting learning experiences for teachers and students to understand the topic of atomic structure and chemical equilibrium.

This research is significant because it makes a valuable contribution to existing knowledge regarding the positive effects of MLNFS-AR on better literacy and numeracy skills. Therefore, this study provides educators and researchers with a deeper understanding of the effectiveness of MLNFS-AR. As a result, MLNFS-AR can be recommended to chemistry teachers as a promising learning method at the secondary education level. It is also recommended that further research investigate the efficient use of MLNFS-AR in improving student literacy and numeracy in the twelfth grade. Finally, a suggestion for future researchers is to conduct research that compares the impact of MLNFS-AR on students' academic achievement, attitudes, and perceptions in secondary schools in various subjects.

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