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Chemistry Mobile Learning of Chemical Elements to Foster Education for Sustainable Development

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Abstract

Students often face difficulties in learning chemical elements due to the large number of concepts that require memorization and limited contextual engagement. At the same time, chemical elements play a vital role in addressing environmental issues, making their understanding essential for advancing Education for Sustainable Development (ESD). This study aimed to develop an Android-based Chemistry Mobile Learning (CML) application in the form of an educational game to promote ESD-oriented chemistry learning. The development followed the ADDIE model (Analyze, Design, Develop, Implement, and Evaluate). The CML application was validated by six expert reviewers, resulting in Aiken's V scores of 0.91 and 0.93, indicating a high level of validity. Student feedback showed that 91% rated the learning experience as "Very Good." The results suggest that the developed CML tool is both feasible and practical for classroom implementation. It enhances student engagement, supports meaningful learning, and fosters sustainability-oriented thinking in chemistry education.

Keywords: chemical elements, chemistry mobile learning, education for sustainable development

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1. Introduction

Application of technology in education is essential in the face of the rapid and impending advancement of digital technologies in all areas, including education (Aisyah et al., 2020; Wang et al., 2024). A promising path for such application is the utilization of smartphones in the learning process that can be flexible to the requirements of the learners and enable technology-aided education (Adesti & Nurkholimah, 2020). Mobile learning, as a unique genre of digital learning facilitated through smartphone technology, offers a mobile learning environment that transcends the boundaries of physical classroom environments. Learning media serve as an interface of connection between learning materials and learners. Utilizing the innovative application of mobile learning, learning experiences can be extended beyond physical classrooms. Besides, the use of highly technologically advanced media has been found to raise cognitive achievement and motivational interest among students (Yektyastuti & Ikhsan, 2016; Pamungkasih et al., 2024). With Indonesia having approximately 100 million smartphone users—making it the fourth country globally in terms of smartphone users—the application of mobile learning at Indonesian schools is not just feasible but highly prospective. Despite this potential, mobile learning adoption is nevertheless low. Research conducted by Ayu (2016) indicates that teachers mostly use old-fashioned pedagogies and media, such as textbooks and paper worksheets, without fully benefiting from the use of mobile technology. This brings to light a disconnect between available technological resources and the pedagogical practice of the modern era.

As part of Indonesia's curriculum and its emphasis on learner-centered and scientific views of learning, there is an urgent need for learning approaches where learners are actively engaged in constructing skills and knowledge. In this learning model, the role of the teacher shifts to that of the facilitator and guides learners through processes of exploratory and inquiry learning (Handayani & Agustini, 2016). The most challenging area in the teaching of science is chemical elements, which the students find abstract and pictorial. The challenge largely arises from the submicroscopic nature of chemical entities, which are difficult to imagine (Del Carlo & Bodner, 2004; Sjöström & Talanquer, 2014). Observational studies have revealed that education in this field relies mostly on traditional methods such as lectures and printed materials, with fewer interactive media (Nurhalimah et al., 2017). Similarly, a needs analysis conducted by Dwiningsih et al. (2018) on several secondary schools confirmed that 60% of the students mentioned difficulties in understanding chemical elements, mainly due to the fact that 86.7% of the teachers used lectures as their teaching approach and only 40% employed student worksheets (LKS) as supplementary media.

Effective learning of chemical elements is not attained by rote memorization but by thorough conceptual appreciation of chemical reactions and processes. To support such mental processing, the need to design creative teaching media comes in, which facilitates easier access for abstract concepts. A study of Bintiningtiyas and Lutfi (2016) suggests that 70% of students become more active while learning when given material is in educational game format, which can be utilized as a motivational tool as well as a cognitive tool. In addition, the role of chemistry education is pivotal to pushing the agenda of Education for Sustainable Development (ESD) forward (Zidny & Eilks 2020), especially through incorporating environmental principles that motivate students to use chemistry in solving actual environmental problems (Perkasa & Aznam, 2016; Zidny & Eilks, 2022). Minimizing paper consumption through employing digital learning resources is consistent with the sustainability aspects of ESD. Smartphone use in education also needs to be guided by social, economic, and environmental factors, as highlighted in the ESD approach (Latchem, 2018).

In this context, what is needed is the design of interactive Android-based learning media, including learning games, that leverage technology to extend effective learning experiences. Production of these media can be facilitated by provision of software tools, including *Construct 3*. As Hartanto in Herawati et al. (2018) maintains, *Construct 3* is a suitable tool for game development due to its user-friendly interface and minimal programming requirements. Underlying these challenges and opportunities outlined above, this research aims to develop an innovative learning game that will enable the teaching and learning of chemical elements through mobile learning platforms.

2. Research Method

This study used the research and development (R & D) method using the ADDIE model (Analyze, Design, Development, Implementation, and Evaluation) (Branch, 2009). This model is designed according to the needs and characteristics of learning. In addition, the ADDIE model is also systematic, so that it provides researchers with the opportunity to conduct assessments at each stage to minimize the shortcomings of the developed media products (Tegeh et al., 2014). The stages of implementing CML media were carried out to 37 of twelve grade students participant with purposive sampling techniques. Before the trial was carried out, the media product was first tested for its feasibility through validation by by 6 experts. The data processing technique on the validation sheet used the Aiken's data processing technique with a scale of 5 (Aiken, 1985).

The Likert scale questionnaire was used to determine students' responses to the use of CML in learning elemental chemistry. Determining the classification of students' responses to Android-based CML media is by using a Likert scale of 1 to 5 as shown in Table 1.

Table 1. Likert Scale Score

No	Options	Score
1	Strongly agree	5
2	Agree	4
3	Neutral	3
4	Dissagree	2
5	Strongly dissagree	1

The results of the Likert scale questionnaire are then processed based on assessment criteria in a range of values (Sarip et al., 2022) as shown in Table 2.

Table 2. Criteria of Interpretation

No	Interval (%)	Category
1	81-100%	Very good
2	61-80%	Good
3	41-60%	Medium
4	21-40%	Not Good
5	0-20%	Not Really Good

Student responses to the Likert scale questionnaire were also distributed into percentages per statement from a scale of strongly agree to strongly disagree. The results of the quiz in CML were also processed to see student learning outcomes on the material discussed.

3. Result and Discussion

The process of developing CML (Chemistry Mobile Learning) learning media oriented towards Education for Sustainable Development (ESD) was designed using *Construct 3* software assisted by *Canva, Adobe Photoshop, Microsoft Power point* applications by adapting several illustrations from chemistry books, and *Freepik* with free licenses and free copyrights. In the CML learning media that has been developed, it consists of several components, including loading bar, main menu, media information, developer profile, usage instructions, competencies, materials, and game level selection menus listed on the main page (Figure 1).

Figure 1. The Homepage View of CML

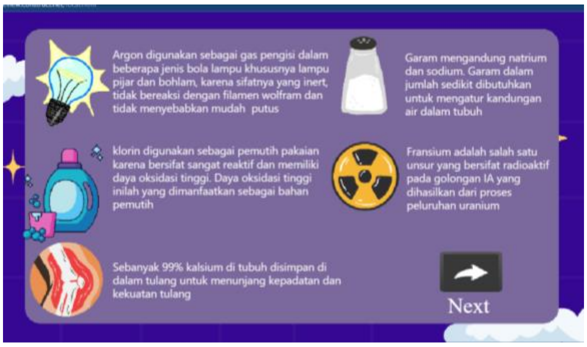
Two main choices of learning materials are provided, specifically chemical elements concepts (Figure 2) and context on sustainability issues that are adjusted to chemical elements topic.

Figure 2. Chemical Elements Learning Content

Figure 2 shows one of the chemical element concepts from the topic of noble gases, specifically focusing on the uses of helium, which include its application as a cooling agent in medical imaging devices such as MRI machines, and its use in filling balloons or blimps due to its lighter-than-air property.

Curriculum analysis has been conducted in this study by describing the curriculum content being applied in secondary school level. Table 3 shows the learning outcome and the visualization of teaching materials in CML that supports the learning achievements.

Table 3. Learning Outcome and the Visualization of Teaching Materials in CML

No	Visualization in CML
1	 
	Learning outcome: Students can analyze data of the physical and chemical properties of the main group elements (noble gas, halogen, alkali, and alkaline)
2	 
	Learning outcome: Students can analyze the benefits and impact of the use of main group elements (noble gas, halogen, alkali, and alkaline soil) on the environment based on sustainable issues that have been presented on learning medial

In CML media, students are given an environmental issue that is closely related to the chemical element material, which is "Invisible e-waste as a threat to the environment and health" (Figure 3).

Figure 3. The Context of Sustainable Issues in CML

This sustainability issue raises the rapid development or revolution of increasingly sophisticated technology, causing many electronic device manufacturers to continue to compete in producing electronic devices that have various superior features (Gaidajis et al., 2010). As a result, people will tend to buy electronic devices just to follow the latest trends without considering the needs of their use. This also causes the service life of electronic devices to be shorter, where people tend to buy electronic devices with the latest models and equipped with sophisticated features rather than sticking with their old electronic devices even though they are still suitable for use. This habit can cause piles of electronic waste or e-waste which are very dangerous for the environment and even health.

This is because electronic devices contain various kinds of hazardous chemical elements that can even be active along with use or not use. The chemicals contained in electronic devices also cannot be broken down naturally, so they can damage and pollute the environment if not handled properly (Bandyopadhyay, 2008).

Referring to Indonesian Government Regulation Number 27 of 2020 concerning specific waste management, electronic waste is included in waste containing Hazardous and Toxic Materials (B3 Waste) which can have a negative impact on humans and the environment if not handled properly. Some chemicals commonly contained in e-waste are mercury, lead, chromium, cadmium, arsenic, and so on. Improper handling of e-waste can cause environmental and even health problems. For example, the e-waste recycling process with the soldering process aims to take only the gold element and ignores other elements which can cause air pollution. Where the remaining waste from e-waste extraction can pollute the soil, rice fields, fields and affect the harvest for areas around the recycling site. In addition, the process of burning electronic waste will also form a hazardous compound, specifically polybrominated diphenyl ethers (PBDE) which are persistent and carcinogenic. Thus, it causes disruption of the hormone system which interferes with fetal growth and the body's immune system (Wang et al., 2011). Thus, this issue is closely related to the material on chemical elements and students can be stimulated to innovate in using chemistry as a solution to environmental problems.

CML media also has an interactive game feature that can motivate students to learn. The games in this media provide four types of game levels with different levels and question content at each level. As at level one, a game is provided to match answers with questions about the use and benefits of main group chemical elements in everyday life (Figure 4), at level two a quiz game is provided about the chemical and physical properties of main group elements, at level three a word-composing game is provided about the process of providing main group elements, while at level four a forms game is provided containing trigger questions about sustainability issues related to elemental chemical material, namely "Invisible e-waste as a threat to the environment and health". The forms game at level four is intended to meet the criteria for students' understanding of Education for Sustainable Development presented in the CML learning media.

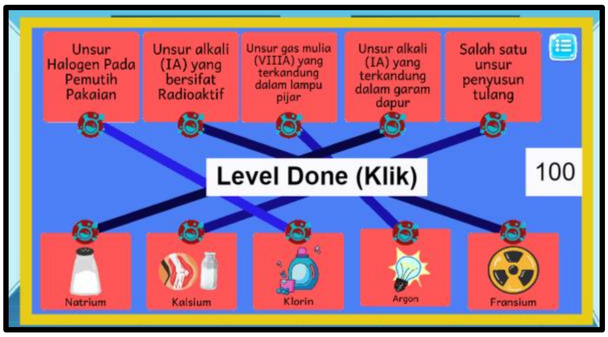


Figure 4. Games Quiz in CML

According to Cebrián and Junyent (2015) the ESD competencies consists of Envisioning, Critical Thinking, Participation in Decision Making, Partnership, and Systematic Thinking. Presenting sustainability issues in learning media allows students to gain a more holistic view of real-life problems. For example, in the context of learning about cleaning soap, students can learn about the aspects of compounds and chemical reactions in the manufacturing process. In addition, students can also learn about the quality of the soap based on its physical use. Thus, students can analyze whether the soap used is safe for the environment and health, if it is dangerous, students can explore alternative resources that are more environmentally friendly and economical (Zidny et al., 2021). The game level in the media is used as an evaluation of the questions. The questions aim to measure and identify how students' competencies have been achieved after using learning media.

Validation conducted in this study was tested on six validators, including two chemistry education lecturers and four validators from chemistry teachers at high schools, with an error rate of 5%. In the validation of material experts and media experts with six validators and an error rate of 5% the results of the Aiken's analysis of the V table value were more than equal to 0.79 (Aiken, 1985). The validity value of the material can be seen in Figure 5.

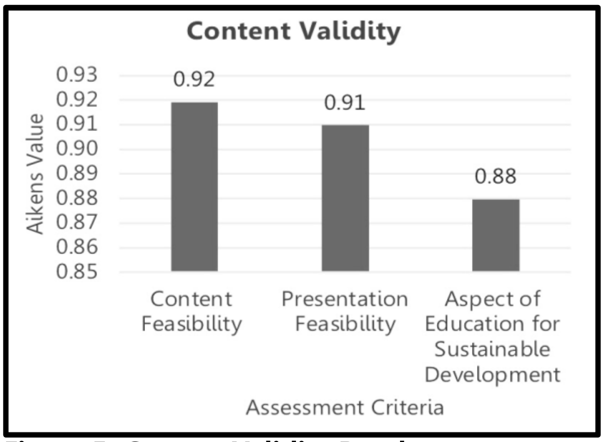


Figure 5. Content Validity Results

Based on Figure 5, it is known that the validation of the material is divided into three aspects with a score of 0.92 for the aspect of content feasibility, a score of 0.91 for the aspect of presentation feasibility, and 0.88 for the aspect of Education for Sustainable Development. Thus, from the results of the validity, the average score of V count against the validity of the material expert is 0.91. Thus, the item is declared valid or worthy of being tested because it is greater than or equal to V table, which is 0.79 with improvements (Aiken, 1985).

The suggestion from the validator that the presentation of several material layouts on the CML media looks monotone because the presentation of the material is only presented in text, so it looks very monotonous. Thus, the authors added several illustrations of images or videos and reduced the discussion of the material, so that it is short, concise, and clear. CML also presenting images, videos, audio and even interactive animations. Thus, the resulting learning media also attracts the curiosity of students to use it. The use of multimedia can foster students' learning motivation (Shilpa & Sunita, 2016; Sulistyono, 2016). The results of media validity can be seen in Figure 6.

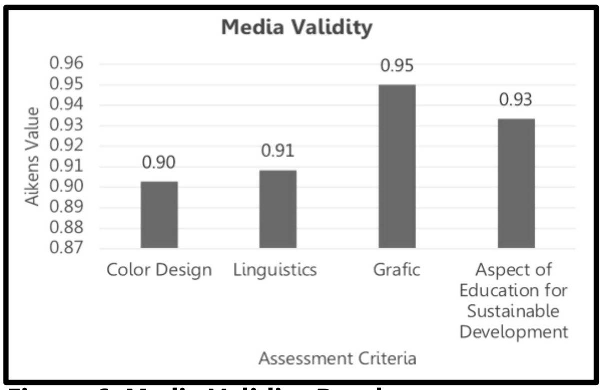


Figure 6. Media Validity Results

Based on Figure 6, the media validation consists of four aspects, specifically color design, use of words or language (linguistic), graphic images, and aspect of Education for Sustainable Development (ESD). The result of the calculated V value for each aspect are 0.9 for the color design, 0.91 for the use of words or language, 0.95 for the graphic image, and 0.93 for the ESD. Thus, from the results of the validity, the average result of the calculated V value for the validity of the media expert is 0.93. Thus, the item is declared valid or worthy of being tested because it is greater than or equal to the V table, which is 0.79 with improvements (Aiken, 1985). The validator's suggestion is that using a font that is too small can cause users to feel uncomfortable when reading material on learning media. To meet the readability criteria, the ideal font size is 24 pt accompanied by the selection of appropriate media colors and backgrounds, so that learning media can be comfortable to read, view, and use (Nurseto, 2011).

After the CML (Chemistry Mobile Learning) learning media was declared valid and feasible for testing. So, the next step is to find out the response of media use to students who were tested on 37 respondents through purposive sampling techniques. Through this stage, data was obtained, the response questionnaire reviewed aspects of media operation, usage reactions, practicality, and Education for

Sustainable Development. The research was conducted in two meetings. The first meeting was scheduled as an introduction to the product and installation of the CML learning media product, while the second meeting was scheduled as the use of the CML learning media product. Then, after using the CML media product, students will fill out a response questionnaire. This aims to determine the practicality of using the CML learning media which will later be processed and the percentage of its use in the learning process will be calculated. The results of the percentage of student response questionnaires can be seen in Figure 7.

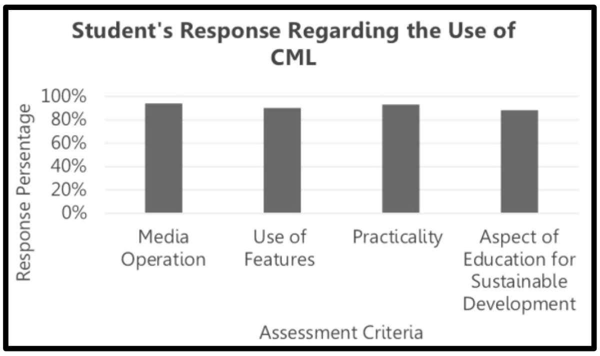


Figure 7. Student's Response Regarding the Use of CML

Based on Figure 7, it is known that the student response questionnaire consists of four aspects, including media operation, use of features, practicality, and aspect of Education for Sustainable Development. The percentage results for each aspect are 94% for the media operation aspect, 90% for the usage reaction aspect, 93% for the practicality aspect, and 88% for the Education for Sustainable Development aspect. Thus, with the percentage results, the average percentage of student responses to media use is 91% with the criteria of "very good". This is because based on filling out the response questionnaire, the average student stated that they strongly agree or agree with each statement item. In the questionnaire, students stated that they agree that the CML learning media is easy to use because the instructions for use are clear.

In addition, the buttons on the learning media also function properly. Thus, students are comfortable using CML media in learning. According to (Rivai & Sudjana, 2009), there are several indicators that can be used to measure the practicality of media use for learning. One of the indicators is the ease of use of learning media for both teachers and students, so that with the ease of use, the delivery of information on the media will be more optimal. Students agreed that CML learning media is very interesting because it presents several illustrations that support understanding of concepts. In addition, evaluation questions on CML learning media are also presented with a game, so that they can attract students' interest in learning, because according to research (Bintiningtiyas & Lutfi, 2016) as many as 70% of students are interested if learning is presented in the form of games. In addition, students agreed that CML learning media is very practical because it can be used anytime and anywhere, and its use does not have to be accompanied by a teacher (self-learning). This is because CML media integrates technology in its use, which is Android-based. So, with just a smartphone, students can use CML media in the learning process. Because currently, the younger generation prefers the use of technology-integrated media in their daily activities. One of them is Android-based media (Widiastuti, 2018).

The younger generation is now dubbed as digital natives, a generation that grows and grows along with the development of digital technology. Therefore, the use of digital learning resources is intended for students as a self-directed learning approach (Kozma, 1991; Putra & Budiningsih, 2023).

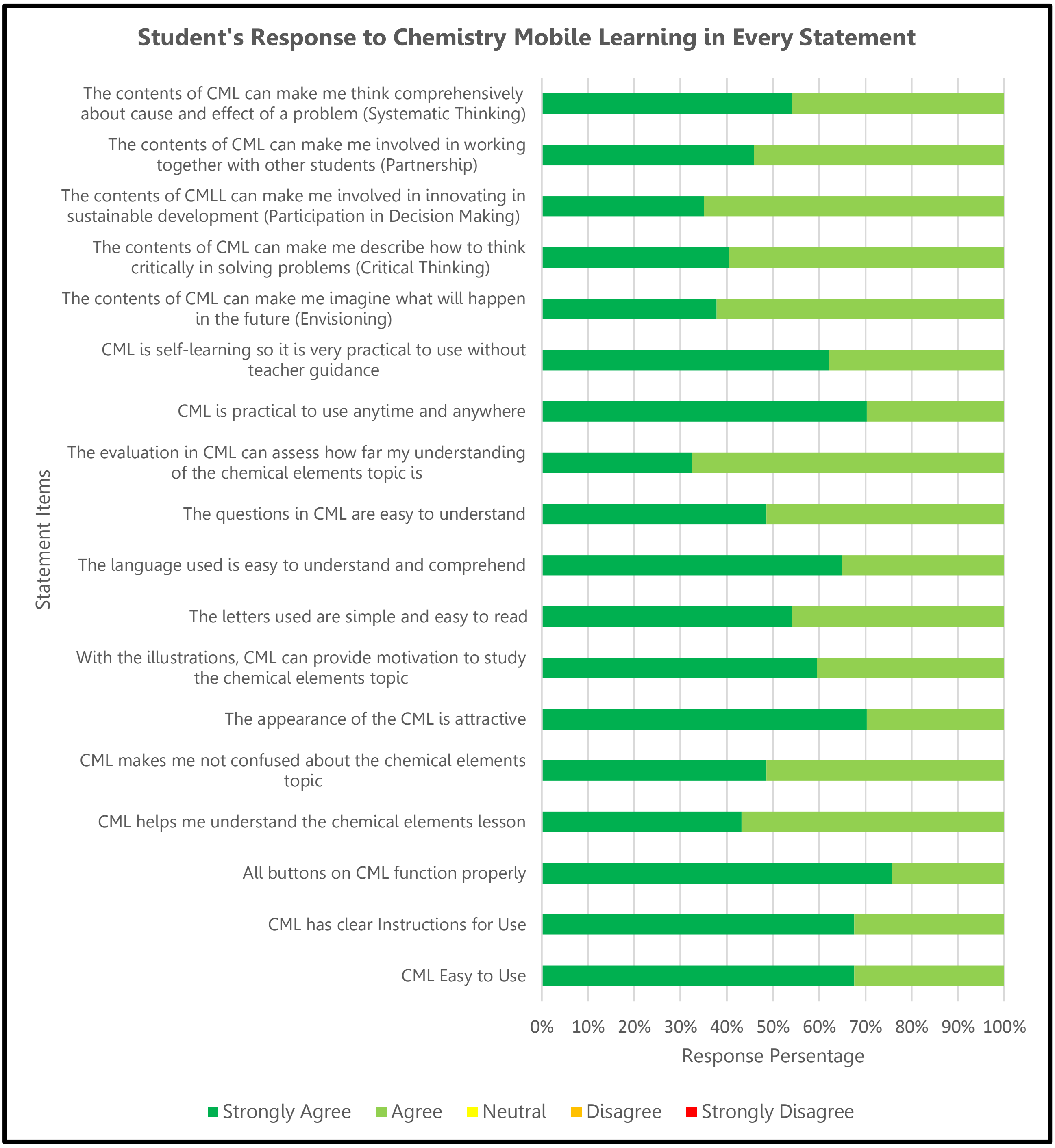


Figure 8. Graph of Percentage of Student Statements

Based on the student's response in every statement item of questionnaire (Figure 8), the evaluation of the Chemistry Mobile Learning (CML) application revealed overwhelmingly positive student responses. As shown in the figures 8, the majority of statement items received a significant percentage of "Strongly Agree" and "Agree" responses, indicating high levels of user satisfaction and perceived effectiveness. The statements relating to systematic thinking, partnership, critical thinking, and envisioning had positive responses above 70%. This suggests that CML effectively encourages higher order thinking skills, supporting the findings of other studies emphasizing the role of digital tools in enhancing critical and systematic thinking (Aliyanti et al., 2025; Hwang & Chang, 2011;

Wu & Shah, 2004). Statements about usability—such as ease of use, clarity of instructions, and functional buttons—also had more than 80% positive responses, confirming that the application design was student-friendly and met their expectations. This aligns with prior work showing that user-friendly interfaces in mobile learning platforms lead to better engagement and understanding (Alrasheedi et al., 2015).

Regarding content comprehension, over 75% of respondents agreed that CML helped them understand the chemical elements lesson, and the illustrations provided motivation for study. This echoes studies by Wu and Shah (2004) highlighting that visual aids and interactive content significantly boost learning in chemistry. Interestingly, a few items—particularly the statement about the evaluation in CML helping to assess understanding—had a higher proportion of neutral responses, suggesting a potential area for improvement in feedback or self-assessment features. Overall, the positive responses underscore the CML application's effectiveness in fostering student-centered learning and active engagement. These findings validate that digital tools like CML can transform chemistry learning by making abstract concepts more accessible and encouraging student autonomy (Hwang & Chang, 2011; Tarchi et al., 2021).

It is known that in the questionnaire, the students' responses to the Education for Sustainable Development aspect received a good response with the criteria of "very good". In the CML learning media, the measurement of the Education for Sustainable Development aspect is applied according to its syntax, specifically envisioning, Critical Thinking, Participation in Decision Making, Partnership, and Systematic Thinking (Rahman et al., 2019), where the measurement of the Education for Sustainable Development syntax in the learning media is presented in the trigger questions at level four of the game. Thus, the achievement of the Education for Sustainable Development syntax in students after using this CML learning media can be seen from the student response questionnaire on the Education for Sustainable Development aspect, as well as the results of student answers at level four of the game. The envisioning stage is the stage for students to imagine a better future (Meadows, 2014). In the CML learning media, this characteristic is presented in a sustainability issue, namely "Invisible e-waste as a threat to the environment and health", so that students are expected to be able to imagine events that will occur if the event is repeated. Then, students also relate it to the chemical element material that has been studied in the chemical element material layout in the CML learning media.

Based on the filling in of the response questionnaire, 38% of students stated that they strongly agreed with the envisioning statement item, and 62% of other students stated that they agreed with the envisioning statement item. Thus, this envisioning statement item received a good response. The critical thinking stage includes the skill of expressing opinions after carrying out a deep-thinking process about an event by involving logical reasoning which then makes decisions or solves problems (Lai, 2011). In the CML learning media, this characteristic is presented in a trigger question at level 4 of the game as an essay question. According to Abidin (2016), the assessment of critical thinking characteristics can be assessed through essay questions, through essay questions students will convey an innovation or new idea that is original or just an expression of ideas in a new way. Based on the filling out of the response questionnaire, 41% of students stated that they strongly agreed with the critical thinking statement item, and 59% of other students stated that they agreed with the critical thinking statement item. Thus, this critical thinking statement item received a good response.

According to Australian Research Institute in Education and Sustainability, the participation in decision making stage is a characteristic that stimulates students to integrate information into a decision on sustainable development on sustainability issues that have been presented. The advantage of this stimulation is that it is able to provide support for students to create a solution to a particular problem (Tilbury & Wortman, 2004). Based on the completion of the response questionnaire, 35% of students stated that they strongly agreed with the participation in decision making statement item, and 65% of other students stated that they agreed with the participation in decision making statement item. Thus, this participation in decision making statement item received a good response. The partnership stage is a characteristic that can be used to stimulate students to be able to synergize with other students to solve a problem (Gunamantha, 2010). Based on the filling of the response questionnaire, 46% of students stated that they strongly agreed with the partnership statement item, and 54% of other students stated that they agreed with the partnership statement item. Thus, this partnership statement item received a good response. The systematic thinking stage is a characteristic that can stimulate students to analyze problems in a complex way so that students are able to know the cause and effect of a problem (Gunamantha, 2010). Based on the filling of the response questionnaire, 54% of students stated that they strongly agreed with the systematic thinking statement item, and 45% of other students stated that they agreed with the systematic thinking statement item. Thus, this systematic thinking statement item received a good response. In addition to being measured through a response questionnaire, the measurement of the syntax of Education for Sustainable Development can be seen from the results of each student's answers at level 4. Figure 9 below presents the average learning outcomes of students on the CML learning media.

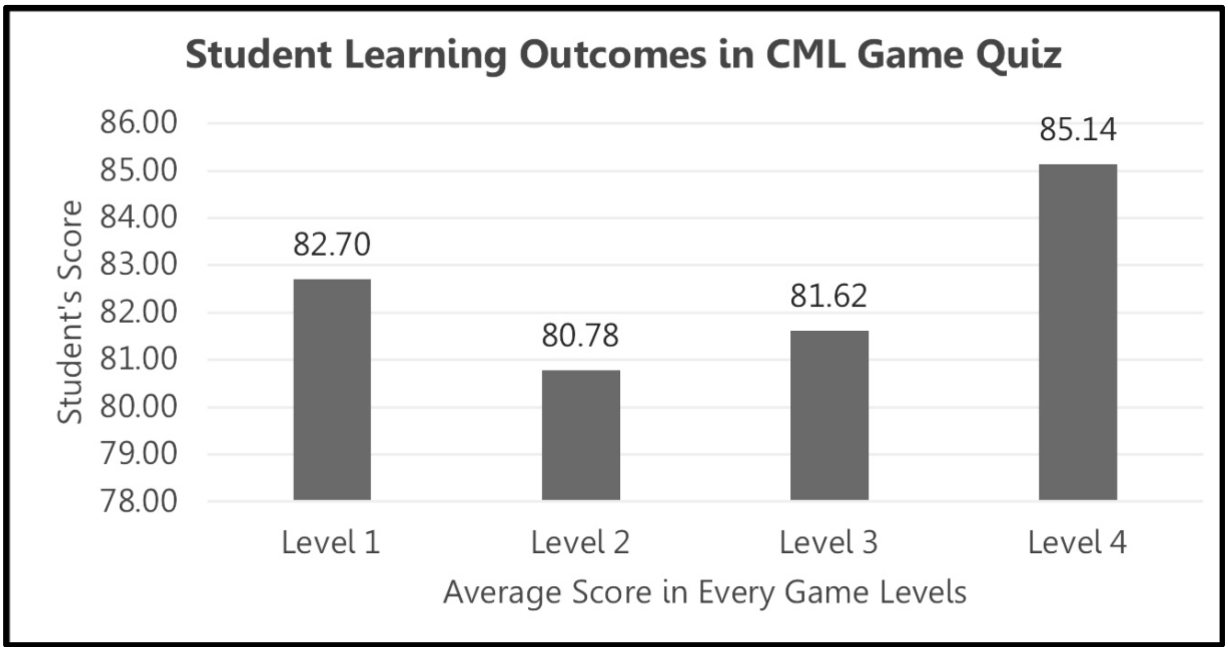


Figure 9. Average of Student Learning Outcomes on CML Media

It is known that the average learning outcomes of students at level 4 obtained the highest score, which is 85.14. Thus, from the average results, students are declared to have completed because they exceed the KKM (Minimum Completion Criteria) which is more than 75. Thus, it can be stated that CML learning media can stimulate students according to the characteristics or syntax of Education for Sustainable Development after understanding the learning material, analyzing sustainability issues, and answering questions or evaluation questions available on the CML learning media.

4. Conclusion

The Chemistry Mobile Learning (CML) media was successfully developed using the Android platform with a focus on the topic of chemical elements and aligned with the principles of Education for Sustainable Development (ESD). Validation of the CML media involved six experts and applied Aiken's V formula with a 5% error margin ($V_{count} \geq V_{table}$, where V_{table} = 0.79). The content expert validation score reached 0.91, and the media expert score was 0.93—both falling into the "Valid" category, indicating the product is suitable for limited trials with minor revisions. Student response to the use of CML was positive, with 91% of students rating it in the "Very Good" category. Specifically, 54% of students responded, "Strongly Agree" and 46% responded "Agree" to the usability and effectiveness of the media. Furthermore, student learning outcomes surpassed the Minimum Completion Criteria (KKM ≥ 75), achieving an average score of 82.6. Based on these findings, the CML learning media is deemed both feasible and practical for classroom use. It effectively supports meaningful and sustainable chemistry learning, making it a valuable tool for enhancing student engagement and achievement in line with ESD goals.

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