Gamified Chemistry Learning AR Application for 10th Grade Student in Indonesia

Glenn R. R. Purnama, Seng Hansun, Marcel B. Kristanda

Abstract: One of the main reasons for a students’ lack of interest in learning or studying school's subjects is the lack of motivational drive. On the other hand, they are more interested in playing (and learning) through digital games. Therefore, in this study, we tried to increase the student’s motivation in learning a school’s subject, i.e., Chemistry, using Augmented Reality (AR) technology combined with Gamification method. In designing and implementing Gamification method into AR application, we used the Player Centered Design framework, with seven game mechanics, i.e., point, leaderboards, levels, challenges, badges, constraints with urgent optimism, and rewards. The application has then been tested to 30 respondents, i.e., 10th-grade students in a private course in the Bandung region, Indonesia. To monitor the user's motivation, we used the ARCS model of motivational design. Based on the evaluation result, we find that respondents of this study feel attracted to use the gamified AR application in learning Chemistry lesson. Gamification method can motivate learners related to factors in the ARCS model of motivational design and the effectiveness of game mechanics. Findings from this study can inform the teachers, especially the instructional designers, the benefit of applying AR technology combined with Gamification method in increasing student’s motivation in learning a school’s subject.

Index Terms: Augmented Reality, Gamification, generation Z, motivation drive, player-centered design.

I. INTRODUCTION

Education is an effort made by the State to achieve a goal that is the intellectual life of the nation [1]. One of the main problems in learning in the field of formal education is the low absorption of learners because the learning conditions are still conventional [2]. Learners who are undergoing formal education at this time are the people who belong to Generation Z. Generation Z is the people born around 1995 to 2010. This generation Z is the first generation that was born when the internet and various other technologies have become available. Several studies have shown the brain structure of the generation Z to be better in the concept of complex visual imagery. The part of the brain responsible for processing the visual image becomes much better than the previous generations. This is a more effective generation when visual learning techniques are incorporated in the learning process than using conventional ways, as usual in the classroom [3]. One way to apply visual learning techniques is by using Augmented Reality technology. Augmented Reality (AR) is a technology that combines the real world and virtual world through the addition of computer-made objects in real-world view with real-time as well [4]. Some researchers suggest that learners use AR to strengthen motivation in learning and improve education in terms of practices that resemble genuine or real experiences [5]. With this, AR technology can be an effective tool for applying visual learning techniques. Experts are trying to apply AR in various school subjects like Chemistry, Mathematics, Biology, Physics, and others [4]. One of the possible subjects in applying AR as a visual learning technique is Chemistry. This is because Chemistry belongs to the visual sciences that have an important role in daily practice. For example, in investigating natural phenomena such as molecules, atoms, and subatomic particles, Chemists have made various chemical representations such as molecular models, chemical structures, formulas, equations, and symbols [6]. This chemical representation presents information that may be elusive if not delivered efficiently through visual display form Larkin & Simon [7]. In Chemistry, as well as on other scientific topics, the ability to visualize three-dimensional shapes is necessary [8]. Integrating Computer Graphics with three-dimensional objects is an effective way to improve visualization skills in the content of scientific subjects [9]. In 2002, Morten and Voegtlü conducted research by designing and building Augmented Chemistry. Augmented Chemistry is an interactive educational work table that can show atomic or molecular structures in Augmented Reality technology. However, the application in their study is still using a desk computer and limited to some features of Augmented Reality.

Generation Z learners will be more developed in a learning environment that can maximize self-reliance and self-study ability or self-educate [10]. Mobile learning is an extension of e-learning that uses mobile devices and mobile internet that allow for learn-on-the-go [11]. However, e-learning only focuses on the use of digital devices for learning, and it provides little motivation. Meanwhile, one of the goals of instructional applications should be the motivational impetus for learners [12]. Several factors determine the success of learning. Motivation seems to be the most important factor that can be targeted by educators in order to improve the quality of learning [13]. One approach to encouraging motivation to learn is through the application of Gamification method [14]. Gamification is a technique of applying the gameplay mechanism in a context that should not be a game, such as education, work, and others [15]. Good Gamification takes advantage of learning theory and needs analysis to balance motivation and ability to achieve desired behavior [16]. Based on problems described above, in this study, an Android mobile learning application was designed and created that intended for learners in high school, especially for the 10th-grade students, to learn Chemistry subject. Augmented Reality (AR) technology is incorporated in the application to apply the visual learning technique, and Gamification method is applied to increase
the students’ motivation in learning Chemistry subject.

II. THEORETICAL BASIS

In this section, we will briefly explain some basic theories and methods incorporated in this research, such as Chemistry lessons, Augmented Reality, Gamification method, and ARCS model.

A. Chemistry

Chemistry is part of the natural science that studies the structure and properties of matter and the energy that accompanies the change [17]. Chemistry is often referred to as the center of knowledge, because Chemistry is needed to study other sciences, such as Physics, Biology, Geography, Environment, Geology, Health, Medicine, History, and even Legal processes require Chemistry. In addition, Chemistry can also be viewed as a science that greatly affects human life. Without Chemistry, human life will be like in ancient or primitive times.

Modern Chemistry was initiated by the French chemist Antoine Laurent Lavoisier by discovering the law of conservation of mass in chemical reactions and exposing the role of oxygen in combustion [18]. The world of Chemistry is based on the atomic theory because the smallest unit of matter is the atom. The atom is the smallest component of the element that will not undergo any change in the chemical reaction. The atomic particles are protons, neutrons, and electrons. The number of protons in the nucleus is called the atomic number. The number of protons and neutrons is called the mass number. The number of atoms in the world is very much, but so many have not been identified. The identified elements are placed on a system called the periodic table of elements.

The periodic table of elements is one of the greatest intellectual achievements in Chemistry [18]. The information contained in it is very numerous and invaluable. This table dates back to the Greek period and still developed today. The periodic table of elements used today is the modern periodic table composed by H.G.J. Moseley, as shown in Figure 1.

![Fig. 1. Modern Periodic Table](image)

In the periodic table, it can be seen various information such as elemental group, elemental period, electron configuration, and periodic properties. The periodic properties include atomic radius, ionization energy, electron affinity, and electronegativity.

B. Augmented Reality

Augmented Reality is the technology that combines the real world and the virtual world through the addition of computer-made objects in real-world view with real-time as well [4]. Unlike Virtual Reality that completely replaces reality, Augmented Reality simply adds or completes the reality.

Augmented Reality applications are divided into two criteria, i.e., marker-based and markerless-based. Marker-based uses a special sign or symbol to display a three-dimensional image on the screen. Meanwhile, for markerless-based does not require a special sign or symbol in displaying three-dimensional images on the screen, but requires a tracking system such as GPS (Global Positioning System), compass, and image detection devices [4].

C. Gamification Method

Gamification is the use of game mechanics for non-gaming contexts [19]. Gamification is different from game-based learning. Game-based learning uses real games to become a learning tool. Meanwhile, Gamification uses only a few game mechanics. Game-based learning has three stages: beginning the game, playing the game, and the end that indicates the user has won in the game. In general, game-based learning is used only once in every game because it means the game has been successfully won and completed. On the other hand, the user can play the game repeatedly in the Gamification to get as many points as possible so that the main goal such as getting the prize is achieved, not just to finish the game alone [20].

For Gamification to be implemented properly, the Gamification framework is used to help determine various aspects of Gamification according to the intended user. One of the frameworks that can be used is Player Centered Design [21].

![Fig. 2. Processes inside Player Centered Design Framework](image)

As in Figure 2, the Player Centered Design framework consists of several processes as follows.

a) Know Your Player: The stage of understanding the user is the first stage in the Player Centered Design framework, using the user persona. A user persona is a data that can represent the characteristics, behavior, and needs of the intended user. User persona can be viewed from various aspects such as gender, generation, goals, aspirations, and others.

b) Identify Mission: Mission refers to the purpose of Gamification activity. Several aspects demonstrate effective missions, namely understanding the scenario, understanding the desired target outcome, and identifying S.M.A.R.T. Mission.

c) Understand Human Motivation: The most effective technique for motivating people is based on player profiles. Several factors, such as generation, gender, and purpose, play a role in determining the right
motivation for the users. Motivational drivers are things that can motivate people based on observations made in the real world and can be used to design exciting experiences in the Gamification world.
d) Apply Mechanics: There are many game mechanics used in video games, but not all of them can be applied to Gamification. The most common game mechanics are points, badges, and leaderboards (PBL triads) [23]. Other game mechanics that can be used in Gamification are levels, progress, challenges, competition, cooperative, and narrative [24].
e) Manage, Monitor, Measure: To ensure the success of Gamification, there are three aspects to be considered: mission management, monitoring player motivation, and measuring the effectiveness of game mechanics.

D. ARCS Model

ARCS Model of Motivational Design was created by John Keller. This model is based on the expectancy-value theory made by Tolman and Lewin in their book “Purposive Behavior in Animals and Men” in 1932 [25]. In ARCS, there are four important factors in the learning process that can encourage and sustain student motivation. These four factors are the acronyms of ARCS, namely Attention, Relevance, Confidence, and Satisfaction [26].

III. METHODOLOGY

The research methodology used in the study is as follow.
a) Literature review

Some basic literature related to the research were learned in this phase. Augmented Reality (AR), Gamification method, ARCS model of motivational design, and the periodic table in Chemistry subject are some of the theories learned during this process and had been presented in the previous section.
b) Designing the AR application

In this phase, we designed the AR application to learn the periodic table in Chemistry subject by using a use case diagram, activity diagram, class diagram, and sequence diagram. We also made a database schema and interface design for the AR application. Moreover, to implement the Gamification system in the AR application, we used the approach of Player Centered Design framework as you can learn in the next subsection (“Player Centered Design Framework for Chemistry Learning Application”).
c) Building the AR application

To build the AR application, we used Unity with C# programming language and Vuforia SDK. The final result of the AR application been built will be explained in the ‘Application Result’ subsection.
d) Testing AR application

The device being used to test the AR application is Samsung Galaxy S5 Android smartphone and some printed markers. The testing was done to 30 respondents who were tenth-grade students. The test location is in Mr. Daniel’s course place at Pasir Salam Street, Bandung City, Indonesia.
e) Evaluation of AR application

At the end of the testing phase, all respondents of this research were given a questionnaire to measure the gamified AR application effectiveness in increasing their motivation to learn Chemistry subject. ARCS Model of Motivational Design was used as a benchmark in organizing the questions and aspects to be measured in the questionnaire.

A. Player Centered Design Framework for Chemistry Learning Application

In this subsection, we explain how did we design and implement a Gamification system to the AR application by using Player Centered Design framework. As explained before, there are several processes to be done as follow.
a) Know Your Player

Understanding players in Generation Z focused on the education section. According to a survey conducted, the characteristics for Generation Z in terms of education are as follows [27, 28].

• 64% agreed that personal success is the most important thing in life.
• 80% think they have more desire to learn than their peers.
• 85% do online researches, and 33% watch online sciences to educate themselves.
• 88% feel optimistic about the personal future.
• 75% consider access to affordable education is a major social issue at the moment.
• The most important topics in life today are grades in schools (85%) and can go to college (78%).
• 52% agree that personal success is the most important thing in life. In the previous generation, the millennial, 46% agreed that personal success is the most important thing in life. There is a 7% higher difference in generation Z.

From the seven points above, it can be concluded that the students of generation Z in education are highly dependent on technology. The students of Generation Z are also very ambitious and competitive in seeking knowledge to get good grades and a bright future.
b) Identify Mission

Missions that want to be realized from applications that are designed and built are as follows.

• Scenario: The students of generation Z learn with technology that is not maximizing the characteristics of Generation Z.
• Target Scenario: The stage of understanding the user is the first stage in the Player Centered Design framework, using the user persona. A user persona is a data that can represent the characteristics, behavior, and needs of the intended user. User persona can be viewed from various aspects such as gender, generation, goals, aspirations, and others.
• Mission: Mission refers to the purpose of Gamification activity. There are several aspects that demonstrate effective missions, namely understanding the scenario, understanding the desired target outcome, and identifying S.M.A.R.T. Mission.
c) Understand Human Motivation

Based on the understanding of players that have been done, the motivational impetus that can be considered is the achievement and feedback.

• Achievement: The generation Z students in the player's understanding are highly competitive and ambitious to achieve goals in education, such as getting good grades, getting into college, and achieving success in life. In this application, the motivation of achievement can be used to motivate learners in studying Chemistry lessons in order to help to get good grades in school.
• Feedback: To be able to achieve goals with
successful and satisfactory value, feedback is needed to find out whether what is done is right or wrong. Therefore, in this application, feedback motivation can be used to motivate students in Chemistry lessons to know the true or wrong answers that were answered when testing. This is necessary so that learners can learn from mistakes and can answer correctly in the next opportunity.

d) Apply Mechanics
Based on a predetermined motivational drive, game mechanics that can be used in this application are as follows.

- **Point**: Point mechanics are used as one of the mechanics to overcome the motivational impulse of feedback because it can provide feedback by adding the number of points if successful in doing something right. In this application, point mechanics are used in the form of experience points and redeemable points. Experience points are applied in the form of points obtained when successfully answering quiz questions in this application. These points are used to identify the level and performance of the users when performing the quiz. Redeemable points are applied in the form of money/coins earned after completing the challenges given in the lesson. The money/coins can be exchanged for extra lives or extra time in the quiz.

- **Leaderboards**: Leaderboards mechanics are used as one of the mechanics to overcome the motivational drive of achievement because it can provide goals to achieve and encouragement to compete with others. In this application, leaderboards mechanics are applied in the form of a leaderboard that is used to see ten players with the highest score on the quiz.

- **Levels**: Levels mechanics are used as one of the mechanics to overcome the motivational drive of achievement because it can indicate application mastery. If all given levels can be completed properly, then the mastery of the material in this application is achieved. In this application, levels mechanics are applied in the form of a quiz level consisting of three levels: level 1, level 2, and a bonus level.

- **Challenges**: Challenges mechanics are used as one of the mechanics to overcome the motivational drive of achievement because challenges give the user a direction to perform a task to get a result or rewards when successfully completing it. In this application, challenges mechanics are applied in the form of challenges that can be solved by the user in the learning mode. If the challenges are successfully completed, the rewards given are redeemable points in the form of money/coins.

- **Badges**: Badges mechanics are used as one of the mechanics to overcome the motivational drive of achievement because badges are visual representations of points that can be achieved after successfully completing a task or activity. In this application, badges mechanics are applied in the form of achievable achievement after the user completes the challenge given during the lesson or gets some points during the quiz.

- **Constraint with urgent optimism**: Constraint with urgent optimism mechanics are used as one of the mechanics to overcome the motivational drive of achievement because constraint with urgent optimism is an obstacle that can give motivation to the user to overcome the obstacle. In this application, constraints with urgent optimism mechanics are applied in the form of deadlines and limits of life in the quiz. The deadline is given 20 seconds per question. The life limit is given three each time a quiz session.

- **Rewards**: Rewards mechanics are used as one of the mechanics to overcome the motivational drive of achievement because rewards can be obtained when the user has accumulated points to redeem the rewards. In this application, rewards mechanics are applied in the form of additional lives and additional time in the quiz that can be obtained by exchanging money/coins collected in the learning mode.

### IV. RESULTS

The application was created with Unity game engine version 5.3.5f1. The application was made for Android devices. In the application, Augmented Reality technology is created using Vuforia Unity SDK v6.2.10. In the use of Vuforia as an SDK, developers must be registered as Vuforia developers and have knowledge related to the use of Vuforia License & Target Manager.

#### A. Application Results

![Fig. 3. Application Main Menu](image)

Figure 3 is a screenshot view of the main menu page of the application. The language used in the application is Bahasa Indonesia since it is targeted for 10th grade student in Indonesia.

![Fig. 4. Learning Menu](image)

If the Learning menu on the main menu is pressed, it will move to a page like Figure 4. 3D objects that appear in the camera are adjusted to the AR marker entered by the user.
If one of the atom elements is pressed, it will bring up the information panel, as shown in Figure 5.

![Information Panel Display](image)

**Fig. 5. Information Panel Display**

If all the elements in the group that are on the challenge being worked on and have been studied entirely, it will bring up the evaluation button at the top left. If the evaluation button is pressed, it will bring up the evaluation panel, as shown in Figure 6. Evaluation is answered by choosing one of the options given.

![Evaluation Panel](image)

**Fig. 6. Evaluation Panel**

If the Level 1 Quiz menu on the main menu is pressed, it will move to a page like Figure 7. Quiz questions are answered by choosing the right or wrong option.

![Level 1 Quiz Menu](image)

**Fig. 7. Level 1 Quiz Menu**

If the Level 2 Quiz menu on the main menu is pressed, it will move to a page like Figure 8. Quiz questions are answered by choosing one of the four options provided by the application.

![Level 2 Quiz Menu](image)

**Fig. 8. Level 2 Quiz Menu**

If the Level 3 Quiz menu on the main menu is pressed, it will move to a page like Figure 9. Quiz questions are answered by bringing the two AR markers that have been detected by the camera to form a molecule.

![Level 3 Quiz Menu](image)

**Fig. 9. Level 3 Quiz Menu**

If the Achievement menu on the main menu is pressed, it will move to a page like Figure 10.

![Achievement Menu](image)

**Fig. 10. Achievement Menu**

If the Rank menu on the main menu is pressed, it will move to a page like Figure 11.

![Leaderboard/ Rank Menu](image)

**Fig. 11. Leaderboard/ Rank Menu**

### B. Evaluation Results

The minimum number of samples required in conducting a study is 30 [29]. Based on this theory, 30 respondents were asked to test the application and fill out the questionnaire afterward. Respondents were obtained from high school students in the tenth grade. The questions asked to the 30 respondents are related to monitoring the user's motivation and the effectiveness of game mechanics according to the Player Centered Design framework. To monitor user motivation, ARCS Model of Motivational Design is used as a reference. The first question up to the twelfth question is a question for user motivation. The thirteenth to the sixteenth question is a question for the effectiveness of mechanical games. Table 1 answered by choosing one of the four options provided by the application.
shows the questionnaire questions that were used in this research.

### Table 1. Questionnaire’s Questions

**Attention**
1. Learning using AR Chemistry application is interesting compared to using a textbook.
2. Challenges and quizzes given are quite challenging.
3. The features provided in the AR Chemistry application are quite varied.

**Relevance**
4. AR Chemistry application helps to understand the Chemistry materials of atomic structures and the periodic table.
5. AR Chemistry application in accordance with the material or curriculum being taught in school.
6. The language and instructions used are easy to understand.

**Confidence**
7. The learning mode helps to complete quiz mode in this application.
8. Challenges and quizzes increase confidence in learning the material.
9. Leaderboards, points, and achievements indicate your ability to do quiz mode.

**Satisfaction**
10. Materials studied in AR Chemistry applications can be applied in school lessons.
11. Leaderboards, points, and achievements can signify success in learning this material.
12. The scoring system is given in the quiz in accordance with the effort you do.

**Engagement**
13. You are satisfied with the features in AR Chemistry application.

**Time**
14. You want to keep using the AR Chemistry application to learn.

**Return on Investment**
15. You are increasingly motivated to study Chemistry using AR Chemistry applications.

**Quality**

Table 2 is the calculation result of the percentage score for each variable used in the questionnaire. It’s based on the respondents’ answers to each question in the questionnaire. Likert Scale was used to help us in calculating the results.

### Table 2. Result of Each Questionnaire Questions

<table>
<thead>
<tr>
<th>Question number</th>
<th>Percentage Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>84.7%</td>
</tr>
<tr>
<td>2</td>
<td>78%</td>
</tr>
<tr>
<td>3</td>
<td>82%</td>
</tr>
<tr>
<td>4</td>
<td>76%</td>
</tr>
<tr>
<td>5</td>
<td>76%</td>
</tr>
<tr>
<td>6</td>
<td>83.3%</td>
</tr>
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<td>7</td>
<td>76.7%</td>
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<td>79.3%</td>
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<tr>
<td>15</td>
<td>81.3%</td>
</tr>
<tr>
<td>16</td>
<td>82.6%</td>
</tr>
</tbody>
</table>

After calculating the percentage score of each question used in the questionnaire, we calculate the percentage of the final score for questions one to three (Attention), four to six (Relevance), seven to nine (Confidence), and ten to twelve (Satisfaction) by calculating the average percentage score of each question in that range for final percentage of each ARCS factor as can be seen in Table 3. For the mechanical game effectiveness factor, no final percentage score is required because each factor is represented by one question.

### Table 3. Overall Results of ARCS Factors

<table>
<thead>
<tr>
<th>ARCS Factor</th>
<th>Overall Percentage Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attention</td>
<td>81.57%</td>
</tr>
<tr>
<td>Relevance</td>
<td>78.43%</td>
</tr>
<tr>
<td>Confidence</td>
<td>79.76%</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>81.1%</td>
</tr>
</tbody>
</table>

From Table 3, we know that Attention is the factor that gets the highest score in the ARCS model. It means that gamified AR application that has been built could attract the player’s attention for learning a Chemistry subject, in this case, the periodic table. Overall, the other factors in ARCS model also have quite high percentage scores ranged from 78% - 82%, which mean that the gamified AR application been built could encourage and sustain the player’s motivation to learn Chemistry subject.

Questions no.13-16 related to the game mechanics’ effectiveness. Engagement factor that relates to the player’s satisfaction in using the gamified AR application to learn a subject gets the highest score of 86.7%. Most of the students who had played the gamified AR application found it was really fun and satisfied with the game mechanics and features implemented in the AR application. They also find it is challenging and could motivate them to study Chemistry, and in return, they want to use it again to help them in learning the subject. Lastly, for the overall quality of game mechanics been implemented to build the gamified AR application for learning Chemistry gets 82.6% score, which implies the Gamification system that had been designed and implemented in the AR application has successfully increased the players (students) motivation to learn a Chemistry subject.
Gamified Chemistry learning application using Augmented Reality technology based on Android has been successfully designed and built. This learning application uses the Player Centered Design framework for Gamification methods. Based on the framework, this learning application has four main modes, i.e., learning chemical elements using AR, quiz, achievement, and ranking. In the four main modes, there are seven game mechanics used, namely points, leaderboards, levels, challenges, badges, constraints with urgent optimism, and rewards.

The testing process of the learning application that has been built has been successfully done, and we got the result that gamified AR application can motivate the learners related to factors in the ARCS Model of Motivational Design. Using the Likert Scale, Attention factor gets the highest result with a value of 81.57%, and Relevance factor gets the lowest result among other ARCS factor with a value of 78.43%. The effectiveness of game mechanics can also be considered effective. Using the Likert Scale, Engagement factor gets the highest result with 86.7% value, and Time factor gets the lowest result among other mechanical game effectiveness factor with 80.6% value.

After all, with the help of Augmented Reality (AR) technology and the right Gamification system been implemented in a learning application, we could get a better learning environment and tool that can increase and maintain the students’ motivation to learn a school subject, in this case, a Chemistry subject.

REFERENCES

AUTHORS PROFILE
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Marcel Bonar Kristanda lives in Jakarta, Indonesia. He received in Bachelor Degree in Computer Science (S.Kom) from Universitas Multimedia Nusantara, Tangerang, Banten, in 2011 and Master of Science in Information Management from Chinese Culture University, Taipei, Taiwan, in 2015. From 2011, he began his career in university as Assistant Lecturer, until he came back from his master study and became Lecturer in the Computer Science Department, Universitas Multimedia Nusantara. Then, he was entrusted to lead the Learning Center Department in 2016 and focused on developing E-Learning Platform and Development. His researches are based on his interests in mobile technology, mobile application development, web development, and software engineering. His extensive researches can be seen in several published papers in both national and international journals and conferences.