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# What Do Students Think of Mobile Chemistry Games?

## Implications for Developing Mobile Learning Games in Chemistry Education

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### ABSTRACT

The impact of digital games on chemistry education has received less attention compared to other scientific fields. This research gap resulted in a limited understanding of how to effectively design mobile chemistry games (MCG) distinct from non-science mobile learning games (MLG). This study aims to explore students' attitudes toward MCG and gather their opinions on the game components using a mixed-methods research design. A total of 698 students from urban universities, categorized into technology, chemistry, and education cohorts based on their academic majors, participated to provide diverse perspectives. The results revealed significant disparities in gameplay experience, particularly in competence and relatedness, between MLG and MCG. Students' educational background significantly influenced their confidence and leisure levels. Concerningly, students exhibited a negative attitude towards MCG. The study provides game developers with a guideline for developing MCG and offers chemistry teachers a framework for selecting appropriate MLG in the context of chemistry education.

### KEYWORDS

Chemistry, Chemistry Games, Game-Based Learning, Learning Games, Mixed Methods Research, Mobile Games, Science Education, Video Games

### INTRODUCTION

Chemistry is widely recognized as a prominent field of science. This scientific discipline is pivotal in understanding various disciplines such as biology, physics, engineering, and medicine. Its foundational principles lay the groundwork for advancements in these diverse fields of study. Given the considerable impact of the chemistry workforce on the contemporary global economy

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(Cambridge Econometrics, 2020), ensuring a steady supply of chemistry graduates is imperative. However, students' interest in chemistry education (CE) has been observed to deteriorate over the past decades (Abulude, 2009; Akram et al., 2017). Factors such as lack of exposure to practical experiences, limited awareness of career opportunities, extensive syllabus coverage, and ineffective teaching methods have been identified as contributors to this decline (Ringer McDonald, 2021; Woldeamanuel et al., 2013). According to Yunus and Ali (2012), students tend to develop a negative attitude when they lack interest in the subject. This negativity subsequently affects their engagement in related activities (Lipnevich et al., 2016). Unfortunately, Hassan et al. (2015) found that students with a negative attitude often experience lower academic performance when compared to those with a positive attitude. The abstract nature of many chemistry concepts (e.g., atomic and molecular structures) exacerbates this problem as it presents challenges for students in observing real-life phenomena (Ahmad et al., 2023). The conventional approach of teaching chemistry as a collection of isolated facts, without relating it to students' everyday experiences, further impedes their ability to grasp its relevance (van Dinther et al., 2023).

To address these challenges, numerous interventions have been implemented and evaluated in CE. Some examples include adaptive learning technology (Fautch, 2019), intelligent tutoring system (Theis, 2020), case-based learning instruction (Dewi et al., 2022), cooperative learning pedagogy (David Agwu & Nmadu, 2023), flipped learning approach (Brady & Voronova, 2023), virtual simulation experiments (Hou et al., 2023), and educational games (Roy et al., 2023). CE utilizes these teaching methods to accomplish various academic goals, which include offering hands-on experiences, cultivating awareness of career prospects, nurturing positive attitudes and involvement, and establishing a connection between the subject matter and students' daily lives. As emphasized in a systematic review (Byusa et al., 2022), game-based learning is one of the highly beneficial instructional approaches that foster students' conceptual comprehension of chemistry. Furthermore, it enhances their motivation to engage in the learning process while deriving enjoyment from making sense of the acquired knowledge (Li & He, 2023). Over the past few years, there has been a notable increase in interest towards the digitization of game-based learning as an effective method to enhance CE (e.g., Chee & Tan, 2012; Hermanns & Keller, 2022; Roy et al., 2023; Winter et al., 2016). Referred to as digital game-based learning (DGBL), it involves incorporating educational content and objectives within video games or game-like environments to actively engage students in the learning process. Many studies have shown the positive impact of DGBL across various academic disciplines (e.g., Fernando et al., 2019; Garcia & Oducado, 2021; Lozano et al., 2023). Therefore, incorporating DGBL in CE can be a promising approach to enhance students' attitudes and learning experiences.

According to Hofstein and Mamlok-Naaman (2011), researchers and educators in the field of science often prioritize the affective domain. When students hold a favorable disposition towards the subject of chemistry, they demonstrate higher levels of motivation, engagement, and persistence in their learning endeavors. These positive outcomes catalyze numerous implementations of DGBL (Chen et al., 2021). Nevertheless, the impact of DGBL in CE remains relatively underexplored compared to other scientific disciplines such as physics, biology, and earth science (Cheng et al., 2015). Consequently, this research study is undertaken to investigate DGBL by scrutinizing mobile learning games (MLG) and mobile chemistry games (MCG). We selected mobile games as the focus of this study because they are more accessible and convenient for students. To avoid confusion between MLG and MCG, the present study makes the following distinction: MLG are educational games designed for subjects other than chemistry, while MCG are casual games that incorporate fundamental chemistry concepts. Both types of games can be played on a mobile device, but they differ in content and the intended context of play. Given the limited research on the implementation of DGBL in CE, it remains unclear which game attributes of MLG should be integrated into MCG. Understanding how players perceive MCG may contribute to the formulation of the technical groundwork needed in developing MLG specifically for CE. In this respect, the following research questions (RQ) have been formulated:

RQ1. Is there a significant difference in gameplay experience between MLG and MCG?
RQ2. How do students' attitudes towards MCG vary across different academic majors?
RQ3. What are the students' perspectives on the features and mechanics of MCG?

According to Erfani et al. (2010), previous gaming experience influences current gameplay performance. Determining whether the gameplay experience is significantly different between MLG and MCG (RQ1) is a necessary preliminary evaluation. Without a significant difference, it suggests that the existing studies on MLG provide a sufficient foundation for understanding MCG. The second step involves examining the attitudes of students toward playing MCG (RQ2). This assessment is essential to emphasize the applicability of MCG mechanics and dynamics. The decision to prioritize attitude as a construct for assessing DGBL is motivated by several reasons. For example, students' performance is influenced by various factors that can be attained through developing a positive learning attitude (Festus & Ekpete, 2012). While cultivating a positive attitude towards learning chemistry may require time and effort (Yunus & Ali, 2012), adopting a positive perspective towards the subject (e.g., through the use of DGBL) can contribute to enhancing students' learning outcomes. In the context of MLG, attitude is one of the main predictors of enjoyment. This aspect is crucial since the enjoyment derived from gaming activities encourages players to become proficient in the game (Touati & Baek, 2017). Lastly, gathering students' perspectives on the different elements of MCG can provide valuable insights for both game developers and chemistry teachers (RQ3). This information can serve as a guide for helping developers understand what aspects are effective and what should be avoided. Additionally, it can assist teachers in selecting the most suitable MCG for educational purposes. Following the work of Howard-Jones et al. (2011), merging the aspects of gaming and learning could face difficulties (e.g., how to link cognition and emotion) when a game is not built with the necessary foundation.

## LITERATURE REVIEW

### Students' Attitude Towards Playing Digital Games

Although the literature on students' attitudes toward playing MCG is limited, several studies have explored this aspect in other disciplines within the context of DGBL. For instance, researchers (e.g., Bragg, 2007; Mavridis et al., 2017) have utilized digital games as supplementary teaching tools in mathematics education and found that the implementation of DGBL positively influenced students' attitudes towards the subject. This positive impact can be attributed to the enjoyable learning experience during gameplay (Howard, 2023; Valderama et al., 2022), which potentially leads to a shift in attitudes and an increased appreciation for mathematical concepts. Notably, this finding underscores the significant motivational appeal of DGBL, making even complex subjects like Mathematics more engaging and enjoyable (Lozano et al., 2023). Similar findings have been observed in other fields (Vlachopoulos & Makri, 2017; Wang et al., 2022) where students have displayed high interest and positive attitudes when digital games are integrated into the learning process (Revano & Garcia, 2021; Vahldick et al., 2014). Considering the success of integrating games into challenging courses, there is no reason for CE to fall behind. However, given the potential variations in students' responses when it comes to science-based concepts, it becomes crucial to investigate their attitudes toward MCG specifically.

### Implementation of Game-Based Chemistry Learning

As the influence of DGBL continues to expand in the field of education, an increasing number of digital games tailored for CE are being proposed and developed. For instance, a multiplayer game called "Legend of Alkhimia" utilized three-dimensional environments and a virtual chemistry lab to facilitate the learning of chemistry concepts (Chee & Tan, 2012). Implementing this game as a classroom intervention in CE resulted in significant improvements in perceptions and attitudes towards the subject matter, with the intervention class outperforming the control class. Similarly, Winter et al. (2016) reported positive outcomes with a game designed to teach organic chemistry, specifically focusing on the ring flip of cyclohexane. The game incorporated mechanics that required players to accurately draw the bond using the correct angle, based on the two different conformational isomers of cyclohexane. In another study by Jones et al. (2018), a multilevel game was introduced. Players need to solve puzzles related to various organic chemistry topics, including functional group identification, structure classification, intermolecular forces, isomers, chiral centers, and the naming of molecules. Upon completing all six levels, students expressed that the game helped them recall organic chemistry concepts they had previously forgotten. It is important to note that these examples of DGBL were specifically developed for CE, whereas the availability of MCG in the marketplace may primarily focus on entertainment rather than educational purposes. Consequently, the challenge of translating scientific puzzles into intuitive digital games should not be overlooked. If a game fails to achieve its intended goal, such as enabling players to solve puzzles without requiring advanced chemistry knowledge, frustration may arise, potentially diminishing the motivational appeal of DGBL.

### Deployment of DGBL in Non-Science Education

Catalyzed by constant technological innovations, DGBL has emerged as a crucial instructional technology in teaching and learning across various disciplines. For instance, Wijers et al. (2010) implemented a location-based geometry game called MobileMath, wherein students were able to identify mathematical concepts within the game. Although the learning outcomes were not specifically measured, students were observed to be engaged and entertained while solving mathematical activities. In a different context, the game Little Botany (Jamonnak & Cheng, 2017) was utilized as a learning tool to enhance plant science education. Students had the opportunity to create their virtual gardens anywhere in the world with the integration of real-time weather data. After three weeks of gameplay, students demonstrated an improved understanding of gardening concepts and increased interest in real-world gardening. Furthermore, the integration of computer algorithms into game mechanics has garnered attention from developers. For example, Revano et al. (2018) employed the Fisher-Yates algorithm to randomize riddles in their logical guessing mobile game. This implementation enhanced the unpredictability of riddle sequencing, making it challenging for students to easily outsmart the game even after resetting. Moreover, the incorporation of DGBL into preschool education curricula has dispelled negative perceptions regarding its use for young children. In a recent preschool game called Kinder Learns, kindergarten teachers and students supported the integration of DGBL as a pedagogical approach in early childhood education (Garcia, 2020). Collectively, these studies suggest that DGBL can be a valuable educational tool, provided that the right game mechanics and components are employed. Therefore, when designing DGBL, it is crucial to carefully examine how a particular game is structured and which components maximize its effectiveness.

## METHODOLOGY

Following the view of Hourigan et al. (2016) that there is no single research instrument that can promise complete truth, the present study employed an embedded mixed-method design. This design approach aims to gather both qualitative and quantitative data, with one form complementing and supporting the other (Creswell, 2020), ultimately enabling a comprehensive exploration of the research questions. As justified by Garcia and Garcia (2023), the integration of quantitative and qualitative approaches is advantageous as it provides a greater depth of understanding for phenomena that cannot be fully comprehended using a single research method. In terms of the specific mixed-methods design, the embedded design was selected because it allows for the simultaneous collection of quantitative and qualitative data. The fundamental principles underlying this design are that a singular data set is inadequate, distinct inquiries necessitate separate answers, and each type of question demands specific types of data. This strategy offers a nuanced and multifaceted perspective on the research topic. A notable aspect of this research design is the secondary role played by one data set, which primarily relies on the other data type. In the present study, the qualitative component serves as a supportive element, enriching and enhancing the insights derived from the quantitative data.

### Setting and Sample

The study participants consisted of undergraduate students enrolled in a chemistry course at the time of the study. A non-probability purposive sampling technique was utilized to select a total of 721 students from twenty (20) chemistry classes representing six Higher Education Institutions (HEIs) across Metro Manila, Philippines. All participants possessed prior experience in playing digital games and have basic knowledge of chemistry concepts. To analyze the results from diverse viewpoints, the responses were categorized into three cohorts: the Education Group (EDUC), the Technology Group (TECH), and the Chemistry Group (CHEM). The EDUC cohort comprised students pursuing bachelor's programs in elementary and secondary education, familiar with educational concepts. The TECH cohort consisted of students pursuing bachelor's programs in information technology and computer science, acquainted with computer and game programming concepts. The CHEM cohort consisted of students pursuing bachelor's programs in chemistry and biochemistry, familiar with chemistry-related concepts. Considering the assumption that MCG may be utilized not only by chemistry majors but also by students from other degree programs with chemistry courses, these three perspectives offer more comprehensive insights into their potential applicability within the classroom setting.

### Research Instrument

As outlined in Appendix A, the research instrument is comprised of a demographic questionnaire, Ubisoft Perceived Experience Questionnaire (UPEQ), Computer Game Attitude Scale (CGAS), and an open-ended feedback form. Consistent with the principles of the self-determination theory (Garcia, 2022), the UPEQ measured players' experience during gameplay. It encompassed three subscales: autonomy, competence, and relatedness (Azadvar & Canossa, 2018). On the other hand, the CGAS assessed players' attitudes toward computer games (Chang et al., 2014). It utilized three subscales: cognition, affection, and behavior, with four factors including confidence, learning, liking, and leisure. The reliability and validity of these instruments were deemed acceptable, supported by Cronbach's alpha values of 0.91 and 0.88 for the UPEQ and CGAS, respectively. Although the CGAS was originally designed for computer games and the UPEQ for general educational games, the items on both scales were deemed appropriate for mobile devices. This decision was based on the understanding that the focus of the CGAS lies in assessing attitudes towards the game itself, rather than the specific device, while the UPEQ seeks to capture the gameplay experience irrespective of the platform. To align with the scope of this study, any references to "computer" in the questionnaires were replaced with "mobile." Furthermore, students were explicitly instructed that the questionnaire items should pertain to a chemistry course, and any mentioned games should be regarded as MCG. Additionally, qualitative data were collected through the feedback form, which incorporated open-ended questions designed to gather students' opinions on MLG, as well as aspects related to game components, features, mechanics, and the overall gameplay experience of MCG.

### Measurement and Analysis

The quantitative data collected from the Learning Management System (LMS) were analyzed using the IBM SPSS statistical analysis program. Descriptive analysis techniques were initially employed to examine the data distribution and present demographic information, including variables such as gender, age, daily gameplay, purpose of playing games, and preferred platform. To assess participant homogeneity, various statistical analyses such as chi-square tests, Fisher's exact tests, and independent t-tests were conducted. The Kruskal-Wallis H Test was utilized to compare CGAS scores among different student cohorts, while the Mann-Whitney U test was used to compare CGAS and UPEQ scores between MLG and MCG. Regarding the qualitative data, a summative content analysis approach (Hsieh & Shannon, 2005) was employed, with codes and keywords pre-identified before analysis. The statements were then grouped based on themes related to the CGAS factors (confidence, learning, liking, and leisure) and the UPEQ dimensions (autonomy, competence, and relatedness) as the initial level of coding. The analysis focused on capturing the context and meaning of statements rather than solely counting the occurrence of related words, thereby avoiding a purely quantitative approach. Additionally, an open coding approach was applied to identify themes and similarities that aligned with the foundations (e.g., narrative design and dynamic assessment) of game-based learning (Plass et al., 2015).

## Procedures and Ethical Considerations

Prior to commencing the study, necessary clearances were obtained from authorities, including school administrators and teachers, to conduct research within their corresponding colleges and universities. Informed consent was obtained from all participants involved in the study. For participants under 18 years of age, separate consent forms were provided to their respective parents. The purpose of the study was communicated to the participants by their teachers before data collection to ensure transparency. Participants were assured of anonymity, and it was emphasized that their responses to the questionnaire would not in any way affect their course grades. After receiving permission, assistance was sought from the Management Information System Director or equivalent position in other HEIs to facilitate the setup of the survey questionnaire within their LMS. Subsequently, a meeting was conducted with program directors to inform them and their faculty members about the data collection process. They were requested to instruct students enrolled in a private LMS classroom to access and complete the research instrument. One week before data collection, students were given instructions to actively

**Figure 1. Screenshots of some of the most popular MCG on the App Store and Play Store: Chemtrix, an arcade puzzle game focusing on building molecules; Molecules, an application that allows manipulation of molecules and substances; Atomas, an incremental puzzle game focusing on the fusion of atoms starting from hydrogen; and Chemistry 2048, a sliding block puzzle game focusing on creating substance**

engage in playing MLG, with a specific focus on those related to science. Moreover, participants were requested to allocate a single session, occurring one hour before the data collection process, to play MCG illustrated in Figure 1. The selection of these chemistry-themed games was based on their distinctive gameplay characteristics and the incorporation of chemistry-related elements, as elaborated in Appendix C. This research study adheres to the ethical principles of multiple HEIs and is conducted in compliance with the Declaration of Helsinki.

## RESULTS AND DISCUSSION

Out of the total number of participants, 719 individuals (99.7%) accessed the questionnaire, with 698 (96.8%) providing responses. However, 21 participants were excluded from the analysis due to inconsistent data, such as discrepancies between player classification and reported daily gameplay. The resulting sample for analysis comprised 677 students (93.8%) who actively participated in the study. Table 1 presents the demographic profile of this sample. The distribution of participants across the three groups was as follows: 214 students (31.6%) belonged to the EDUC group, with 63.2% pursuing a Bachelor of Science in Elementary Education and 36.8% pursuing a Bachelor of Science in Secondary Education. The TECH group included 234 students (34.6%), with 77.5% enrolled in a Bachelor of Science in Information Technology program and 22.5% in a Bachelor of Science in Computer Science program. The CHEM group consisted of 229 students (33.8%), with 72.4% pursuing a Bachelor of Science in Chemistry and 22.5% pursuing a Bachelor of Science in Biochemistry. Most participants were classified as young ($n = 455$, 67.2%) and male ($n = 414$, 61.2%) students. They identified themselves as regular players ($n = 432$, 63.8%) and displayed a preference for mobile devices ($n = 303$, 44.8%) as their gaming platform. The reported gaming duration for relaxation purposes ranged from 1-2 hours per day ($f = 304$, 44.9%). Statistical analysis confirmed the homogeneity of characteristics across the three groups, as there were no significant differences observed ($p > 0.05$).

RQ1. Is there a significant difference in gameplay experience between MLG and MCG?

A Kruskal-Wallis *H* test was conducted to determine if there were significant differences in the UPEQ scores. The analysis aimed to assess whether the groups' scores varied significantly based on students' academic majors. In MLG, the UPEQ scores concerning autonomy ($\chi^2(2) = 14.476$, $p = .192$), competence ($\chi^2(2) = 13.219$, $p = .091$), and relatedness ($\chi^2(2) = 12.421$, $p = .068$) were not statistically significantly different between the groups. This finding indicates that students evaluated MLG similarly regardless of their academic background in education ($3.67 \pm 1.01$), technology ($4.03 \pm 0.88$), and chemistry ($3.89 \pm 0.97$). However, the situation was different for MCG, as the UPEQ scores exhibited statistically significant differences in competence ($\chi^2(2) = 2.234$, $p = .041$) and relatedness ($\chi^2(2) = 3.419$, $p = .043$) but not in autonomy ($\chi^2(2) = 8.491$, $p = .074$). Post hoc analysis through pairwise comparisons revealed significant differences between TECH (median = 2.8) and CHEM (median = 4.2), as well as between EDUC (median = 3.2) and CHEM (median = 4.2). The median scores indicate that non-chemistry majors felt less capable and connected while playing MCG. One possible reason is that the presence of chemistry content allowed CHEM to establish a stronger connection with MCG. The significance of the educational aspect of the game content aligns with findings from other science courses (Voulgari, 2020). On the other hand, a Mann-Whitney *U* test was performed to examine whether UPEQ scores significantly differ according to the game theme. The analysis sought to investigate whether MLG and MCG evoke similar responses in terms of players' perceptions of the game. Consistent with the individual analysis of MCG, the results exhibit statistically significant differences between MCG and MLG in terms of competence ($U = 1058.42$, $p = .007$) and relatedness ($U = 1432.50$, $p = .000$), but not in terms of autonomy ($U = 1788.50$, $p = .298$). These findings suggest that prior studies on

**Table 1. Demographic characteristics of participants**

| Variable | Category | *f* | % |
|---|---|---|---|
| Gender | Male | 543 | 88.7 |
| | Female | 69 | 11.3 |
| Age | Younger < 18 | 411 | 67.2 |
| | Older >= 18 | 201 | 32.8 |
| Program | Bachelor of Science in Information Technology | 191 | 31.2 |
| | Bachelor of Science in Information System | 109 | 17.8 |
| | Bachelor of Science in Computer Engineering | 42 | 6.9 |
| | Bachelor of Science in Chemical Engineering | 56 | 9.2 |
| | Bachelor of Science in Chemistry | 21 | 3.4 |
| | Bachelor of Science in Secondary Education | 127 | 20.8 |
| | Bachelor of Science in Elementary Education | 66 | 10.8 |
| Daily gameplay | Less than 1 hour | 54 | 8.8 |
| | Between 1-2 hours | 111 | 18.1 |
| | Between 3-4 hours | 117 | 19.1 |
| | Between 4-5 hours | 298 | 48.7 |
| | More than 5 hours | 32 | 5.2 |
| Preferred Gaming platform | Personal Computer (PC) | 189 | 30.9 |
| | Nintendo Switch | 2 | 0.3 |
| | PS4/Pro | 48 | 7.8 |
| | Smartphones/Tablets | 350 | 57.2 |
| | Xbox One/X | 9 | 1.5 |
| | VR Headsets | 3 | 0.5 |
| | AR Headsets | 0 | 0 |
| | Mac | 11 | 1.8 |

students' attitudes toward MLG may not directly apply to MCG. This result emphasizes the need for further exploration and investigation into MCG.

Overall, the analyses revealed that both MLG and MCG provide players with a sense of control, whether real or illusory, that complements their preferred playstyle. This aspect holds significant importance, as variables associated with in-game autonomy have been found to increase the likelihood of pursuing in-game goals (e.g., additional learning tasks), directly influence motivation for gameplay, and positively influence post-play mood (Ryan et al., 2006). Akimkhanova et al. (2023) observed similar effects when using interactive games to teach physics and astronomy to children and teenagers. One explanation is that the autonomous will of the players is triggered which led to increased interest and engagement in the learning experience. From a game design and mechanics perspective, enhancing autonomy can be achieved by offering players substantial flexibility in their in-game choices and tasks, as well as allowing them to shape the game narrative in meaningful ways. By providing players with a sense of agency during gameplay, games can establish an emotional connection to the extent that players perceive their virtual avatars as an extension of themselves in the physical world (Garcia et al., 2023).

Another notable difference between MLG and MCG is the focus on feeling capable and effective. MLG promotes a mindset of constant improvement through challenges, whereas MCG do not have the same effect on non-chemistry majors. However, it is crucial to incorporate this missing characteristic into MCG, as competence is closely associated with game enjoyment and changes in well-being before and after gameplay (Ryan et al., 2006). One strategy is to build a cycle of in-game and character progression that instills and maintains a sense of confidence. Garneli et al. (2019) echo the same notion as games can have affective, behavioral, cognitive, and motivational influence in various disciplines, especially in the field of science education. Another technique is for game designers and developers to strategically integrate challenging tasks that are still manageable and achievable based on the players' current rank and abilities. A common practice in MLG is to employ an algorithm that initially presents easier questions or tasks and progressively introduces more demanding challenges as players advance. Unfortunately, MCG also failed to manifest the concept of social belongingness as perceived by a player towards the game environment or other players. Recognizing this gap is crucial, as relatedness has been shown to predict enjoyment and future gameplay (Ryan et al., 2006). Furthermore, since chemistry courses are offered to students in non-science programs as well, the inclusion of relatedness as a prominent game characteristic becomes even more essential for game designers and developers. In today's gaming environments, relatedness is particularly achievable in online multiplayer and local area network games (e.g., Garcia et al., 2022) where players can compete and interact with one another. Most existing MCG are designed to prioritize cognitive development over social interaction, and thus fail to meet the relatedness factor.

RQ2. How do students' attitudes towards MCG vary across different academic majors?

Given the significant difference in gameplay experience between MLG and MCG, it becomes crucial to assess students' attitudes specifically towards MCG rather than relying on existing studies focused on MLG. A Kruskal-Wallis H test was consequently conducted to examine whether CGAS scores significantly differed based on students' academic majors. The results indicated statistically significant differences in confidence ($\chi^2(2) = 3.419$, $p = .043$) and leisure ($\chi^2(2) = 2.929$, $p = .022$), but not on liking ($\chi^2(2) = 11.762$, $p = .925$) and learning ($\chi^2(2) = 10.119$, $p = .907$). Overall, students exhibited a negative attitude towards MCG (median = 2.2).

Regarding confidence, the post hoc analysis revealed significant differences between TECH (median = 2.4) and CHEM (median = 3.4), as well as between EDUC (median = 1.8) and CHEM (median = 3.4). These findings indicate that only CHEM felt confident while playing MCG, while EDUC and TECH did not. One possible explanation for this disparity is that CHEM was able to establish a stronger connection or relatability to the game content. The level of confidence plays a crucial role in influencing the voluntary engagement of players in DGBL (Lu et al., 2014). When students lack confidence in their abilities within the game or struggle to perform tasks effectively, they are less likely to continue playing MCG of their own accord. In a game design context, the confidence of players tends to diminish if they feel powerless or unable to perform tasks proficiently (Ryan et al., 2006). This scenario presents a challenge when dealing with complex subjects that add complexity to the process of transforming scientific puzzles into intuitive digital games. In their experience while developing a game on introductory quantum mechanics, Anupam et al. (2018) had to strike a balance that made the game accessible enough to avoid discouraging inexperienced gamers. Consequently, the difficulty in designing MCG that effectively builds and maintains players' confidence should not be underestimated.

In terms of leisure, the post hoc analysis revealed significant differences between TECH (median = 1.8) and EDUC (median = 3.4), as well as between TECH (median = 1.8) and CHEM (median = 3.6). These results indicate that only TECH did not perceive enjoyment during gameplay. This lack of enjoyment may be attributed to students who have limited prior knowledge of chemistry or possess a low appreciation or liking for the subject. In a survey conducted by Vorderer et al. (2003), a challenge was identified as the most significant determinant of perceived enjoyment for players, as sympathetic arousal is experienced when they complete tasks that match their abilities. It is plausible that students' academic majors, such as chemistry and education, played a role in influencing their liking scores. However, it is essential to recognize that the development of a positive attitude toward learning chemistry takes time (Yunus & Ali, 2012). Therefore, educational game developers should prioritize fostering an appreciation for the game content, second only to the game itself, to ensure effective engagement and enjoyment.

Although there was no significant difference in the learning factor, students assigned a low score (median = 2.4) to MCG. This finding suggests that students struggled to grasp the intended content conveyed by the games. From a cognitive perspective, video games are influenced not only by their content and genre but also by their mechanics. This observation highlights the critical responsibility of game designers and developers to meticulously align the game mechanics with the intended learning goals. By achieving this alignment, the game mechanics can be successfully amalgamated with learning mechanics (Plass et al., 2015). In this regard, caution should be exercised in selecting game elements and mechanics that do not hinder players with limited prior knowledge (Seufert, 2003). If players are unable to complete an in-game task due to a lack of prerequisite knowledge, they are more likely to become frustrated and abandon the game. Similarly, there was no significant difference in terms of leisure. This finding suggests that students did not perceive playing MCG as a potential leisure activity (median = 2.2). While teachers may encourage students to play these games within the classroom setting, this extra gaming time may limit organic gameplay outside the scheduled class and school environment. The compulsory nature of this approach may discourage students' voluntary engagement. This aspect is significant because allocating more time to gameplay independently enhances the opportunity for mastery and a deeper understanding of the subject matter. This aspect holds significance as dedicating more time to independent gameplay offers more opportunities for mastery and a deeper understanding of the subject matter. Increasing students' exposure to gameplay facilitates a relatively easier mastery of the concepts, considering the vast nature of chemistry that cannot be comprehensively learned in a short period (Edomwonyi-otu & Avaa, 2011).

RQ3. What are the students' perspectives on the features and mechanics of MCG?

Recognizing and understanding the key components of a game is crucial, as the effectiveness of cultivating a positive attitude towards a subject primarily relies on how well a game fulfills players' preferences and expectations (Fabricatore, 2007). For the qualitative aspect, the preliminary themes for analysis were derived from the factors of CGAS and UPEQ (see Appendix B). Using an open coding approach, the analysis led to the identification of several significant themes, namely dynamic assessment, narrative design, multiplayer mode, incentive system, aesthetic design, and game mechanics. These themes represent essential elements within the games that contribute to shaping players' experiences and attitudes. By examining these game aspects, educators and developers can gain valuable insights into how these components influence players' engagement, motivation, and overall perception of the game. The findings of this analysis can inform the design and development of effective educational games.

### *Dynamic Assessment*

Players who lack prior knowledge of an academic subject often encounter difficulties when attempting to engage in learning-related tasks, even if those tasks are integrated into a casual game. For instance, Participant 212 acknowledged having "*no prior knowledge*", while participant 223 admitted to having "*no idea about the subject*". Both students developed a dislike for the game and chose to quit. The learning progression cycle failed to initiate due to players being hindered by their inadequate prior knowledge, as also emphasized by the learning factor in the CGAS. This premature termination necessities the implementation of dynamic assessment, allowing MCG to assess players' prior knowledge and adjust its difficulty accordingly. For the implementation to be successful, MCG should provide in-game tutorials that not only teach new players how to play but also explain the scientific and academic aspects of the game. This feature is particularly crucial considering that the scientific content within the MCG may pose challenges for non-science enthusiasts. The effectiveness of in-game tutorials in enhancing engagement within complex games has already been demonstrated by Andersen et al. (2012). These tutorials can be utilized to establish prior knowledge before players engage with the actual game levels. Additionally, they can continue to provide support for continuous learning throughout the game, ultimately contributing to the attainment of the confidence factor within the UPEQ. Whenever possible, the integration of practical experiments (Ahmad et al., 2023) and creative exercises (Shaw, 2023) can be employed to further enhance the understanding and application of the game's content.

### *Narrative Design*

The absence of a narrative design in a game often leads to reduced engagement compared to a game that incorporates a meaningful narrative through elements such as cutscenes, dialogues, scrolling texts, and in-game actions (Cardona-Rivera et al., 2020). According to Breien and Wasson (2021), the lack of a game story demotivates students which often results in waning interest and eventual abandonment of the game. Prior works (e.g., Konstantinos & Michail, 2014) support the notion that a game story serves as a motivator for students, emphasizing the importance of integrating narrative design into DGBL. Therefore, it becomes evident that developers of educational games should utilize meaningful narrative designs to mediate players' interaction and gameplay experiences. In MCG, designers and developers have various options on how to integrate meaningful narrative design. These operators include *performative narratives* that introduce stories at the beginning (e.g., presenting a new chemical element), *experiential narratives* that unfold during gameplay (e.g., animations depicting atom fusion), *augmentary narrativ*es that focus on backstory and layered information (e.g., narrating the story of a chemist on a quest to discover a new chemical element), and *descriptive narratives* that highlight the emergence of a culture within the game (e.g., explaining the importance of learning chemistry concepts through narration). These narrative operators can enhance player engagement and facilitate a deeper understanding of the chemistry concepts being taught, fostering a more immersive and impactful learning experience. By leveraging these diverse narrative approaches, educational game developers can create a cohesive and enriching environment that supports both gameplay enjoyment and educational outcomes (Li & He, 2023; Touati & Baek, 2017).

### *Multiplayer Mode*

Given our inherent social nature, players frequently desire a sense of social connection within the gaming environment or with fellow players (Azadvar & Canossa, 2018). Fortunately, the interactive nature of video games naturally facilitates player-to-player interaction, as the game environment itself serves as a platform for self-expression and community engagement (Garcia et al., 2022). The significance of social interaction in gaming is underscored by the relatedness factor within the UPEQ. To facilitate such interaction, the video game industry commonly incorporates online multiplayer and local area network games. By offering a multiplayer mode, players can choose to either "*collaborate with teammates*" (Participant 567) or "*compete against other players*" (Participant 99), thereby stimulating additional motivation through competition. According to Kirschner et al. (2004), promoting collaborative interaction among players through computer-supported collaborative learning environments has a positive impact on learning outcomes. This claim is supported by Sung and Hwang (2013), who found evidence that a collaborative game-based approach enhances learning achievement and self-efficacy. This approach mirrors the effectiveness of collaborative learning strategies in enhancing the academic achievement of chemistry students

(Nkechinyere & Ordu, 2018). While developing multiplayer games or finding MCG with multiplayer support may pose challenges, these games are warranted due to the predictive relationship between relatedness and enjoyment, as well as future gameplay. In the context of the MCG used in this study, incorporating multiplayer game modes can be achieved by designing scientific puzzles that require two players to cooperate to complete levels or by allowing multiple players to collaborate in solving a puzzle. This strategy is expected to foster a sense of social connectedness and enhancing the learning experience.

### *Incentive System*

Game reward mechanisms and incentive systems, such as scores, special weapons, badges, trophies, and power-ups, play a crucial role in maintaining player excitement throughout gameplay (Hallford & Hallford, 2001; Luluquisin et al., 2021). These elements create anticipation and pleasure for players, motivating them to invest maximum effort in completing in-game tasks. Hao and Chuen-Tsai (2011) further emphasized how game reward systems can drive player progression and advancement. Participant 565 even expressed that "*receiving achievements as prizes during quests*" would keep players motivated. While a scoring system is a common form of reward, its effectiveness is enhanced when displayed on a leaderboard, particularly in multiplayer formats. However, in the absence of an online platform or multiplayer mode, alternative methods can be used to provide in-game incentives. For example, players could be rewarded with special lab equipment upon reaching a specific chemical element. This equipment would then assist them in solving puzzles more easily, adding an element of progression and tangible benefits to their gameplay experience. Another approach is to incorporate random or unexpected rewards based on both anticipated and unforeseen triggers. This strategy creates an element of surprise that could further motivate players. By implementing diverse reward systems and incentive mechanisms, game developers can foster a sense of accomplishment, engagement, and motivation in players throughout the gameplay experience (Frommel & Mandryk, 2022; Tyni et al., 2022).

### *Aesthetic Design*

The concept of game aesthetic encompasses three main aspects: sensory experiences encountered by players, the overlap between digital games and other art forms, and the aesthetic experience through pleasure, emotion, sociability, and form-giving (Simon, 2009). As a fundamental design principle, aesthetics is utilized by game designers to create visual appeal that sets the overall tone and atmosphere of the game. In DGBL environments, the aesthetic considerations serve to enhance players' appreciation of the game and entice them to immerse themselves fully in the gameplay. Interestingly, a game that possesses basic mechanics but features a strong thematic element and appealing aesthetics can still deliver an enjoyable experience. As one participant suggested (Participant 31), if the game revolves around a scientific theme, incorporating "*asset designs like laboratories with equipment such as microscopes*" can enhance the game's immersion. Another idea is to incorporate characters resembling chemists or scientists wearing lab gowns. By incorporating graphics and visual elements that are relevant to the industry or culture depicted in the game, the visual aesthetics become representative of the practical aspects of gameplay (Arayata et al., 2022; Parel et al., 2022). By carefully considering and implementing aesthetics in game design, developers can create visually captivating environments that resonate with players, enhancing their engagement and immersion in the game. The combination of strong thematic elements, appealing graphics, and relevant visual representations contributes to a more compelling and enjoyable gameplay experience.

### *Game Mechanics*

Plass et al. (2015) emphasize the significance of game mechanics as a vital component in a game-based learning foundation that contributes to engagement and motivation in games. In the context of learning games, it is crucial to align the learning objectives with the game mechanics, ensuring that every interaction, activity, quest, and task within the game is designed to support the desired learning outcomes. Without appropriately designed learning mechanics, players may be motivated to play the game without actually deriving meaningful learning from it (Cortez et al., 2022). Participant 63 highlighted that it was easy to "*predict how to solve the next level because it is very obvious since the only difference between levels is the game background and the enemy*". If the game levels lack variation and pose predictable challenges, players may find the game monotonous and opt to play other games instead (Participants 25, 22, 125, 424). For this problem, introducing a variety of rules, procedures, visual aesthetics, and game narrative elements can help establish randomness and dissimilarity across levels, even if the gameplay mechanics remain consistent. For example, after successfully mixing chemicals, the protagonist could be transported to a new setting where the chemicals can be safely utilized. By incorporating elements that provide novelty and surprise, the game can maintain player interest and engagement. In line with traditional classroom approaches, the MCG should strive to facilitate the acquisition of both conceptual knowledge and abstract concepts (Ahmad et al., 2023). This approach suggests that the game should not only focus on surface-level content but also support deeper understanding and comprehension of complex scientific concepts.

### Game Design Framework and Practical Implications

Overall, this study provides several key recommendations as visually presented in Figure 2. First prioritizing dynamic assessment using in-game tutorials is crucial, particularly for players who lack basic knowledge of the subject. These tutorials can guide players and help them overcome initial challenges and misconceptions. Considering the complexity of games with intricate content, dynamic assessment becomes even more essential for facilitating effective learning experiences. To enhance player engagement, the existence of a meaningful narrative design is vital. This aspect can be achieved through the incorporation of cutscenes, dialogues, scrolling texts, and in-game actions, utilizing the appropriate narrative operators. By integrating a compelling storyline, game developers can captivate players and foster a sense of immersion and emotional investment. Facilitating collaborative interaction between players is another important aspect to consider. Multiplayer modes should be implemented to enable players to discover a sense of social belongingness and promote collaborative learning experiences. By encouraging teamwork and cooperation, multiplayer modes enhance engagement and provide opportunities for meaningful interactions among players. The significance of game reward mechanisms and incentive systems cannot be overlooked. These elements contribute to maintaining player excitement and motivate them to exert maximum effort in completing in-game tasks. By incorporating various rewards (e.g., scores, special items, badges, and trophies), game developers can create a sense of achievement and drive players' engagement and motivation. It is crucial to align all these elements, including dynamic assessment, narrative design, multiplayer modes, and reward systems, with the learning objectives of the course. By mapping the learning objectives directly into the game mechanics, every interaction, activity, quest, and task within the game can be aligned with the desired educational outcomes, reinforcing the connection between gameplay and learning. Lastly, the execution of these elements should be accompanied by aesthetical considerations. Visual aesthetics play a significant role in attracting and convincing players to fully immerse themselves in the gameplay experience. Attention to aesthetics can enhance the overall appeal and engagement of the game, making it more appealing and enjoyable for learners.

## CONCLUSION

This study aimed to explore students' attitudes towards MCG and establish a guideline for developing effective educational games in the context of CE using MLG as a reference. Despite the general acceptance of MLG in the education sector, the study found that students displayed a negative attitude towards existing MCG. Furthermore, significant differences were observed in students' scores based on their academic major, particularly in terms of confidence and leisure. Notably,

**Figure 2. Digital game-based learning framework for chemistry education**


there were also significant differences in gameplay experience, specifically in competence and relatedness, between MLG and MCG. These findings are significant because students' attitudes play a crucial role in their academic success and are considered a key predictor of enjoyment in MLG. To counter the negative attitude towards MCG, the study proposes various design principles, including narrative design, game mechanics, incentive systems, multiplayer modes, dynamic assessment, and aesthetic design. These guidelines can provide valuable insights for game developers in designing mobile games for CE and serve as a blueprint for chemistry teachers in selecting appropriate MCG for teaching and learning purposes. While this framework may have specific applicability to CE and mobile platforms, it is essential for future research to validate these guidelines across other disciplines and platforms, such as PC-based games. Comparative studies between course- or platform-specific games can further enhance our understanding of the effectiveness and applicability of the outlined principles. By expanding research in both science and non-science courses, we can continue to refine and optimize DGBL experiences, ultimately benefiting students' engagement, motivation, and academic achievements.

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# APPENDIX A. RESEARCH INSTRUMENTS

## Section 1

### Ubisoft perceived experience questionnaire

| Factors and Items | Strongly Agree | Agree | Disagree | Strongly Disagree |
|---|---|---|---|---|
| *Autonomy* | | | | |
| I had the freedom to determine my own gameplay approach. | ☐ | ☐ | ☐ | ☐ |
| The game allowed me to play according to my preferences. | ☐ | ☐ | ☐ | ☐ |
| I had the autonomy to choose how I wanted to play the game. | ☐ | ☐ | ☐ | ☐ |
| I was faced with significant decisions during gameplay. | ☐ | ☐ | ☐ | ☐ |
| My choices directly influenced the game's outcome. | ☐ | ☐ | ☐ | ☐ |
| My actions had a noticeable impact on the gameplay experience. | ☐ | ☐ | ☐ | ☐ |
| *Competence* | | | | |
| Over time, my gameplay skills improved. | ☐ | ☐ | ☐ | ☐ |
| I have seen significant improvement in my gaming abilities. | ☐ | ☐ | ☐ | ☐ |
| Through practice, I mastered the game. | ☐ | ☐ | ☐ | ☐ |
| I excelled at playing. | ☐ | ☐ | ☐ | ☐ |
| I felt confident in my gaming competence. | ☐ | ☐ | ☐ | ☐ |
| I felt highly capable and effective while playing. | ☐ | ☐ | ☐ | ☐ |
| *Relatedness* | | | | |
| I genuinely enjoy the company of the people I play with. | ☐ | ☐ | ☐ | ☐ |
| The players I regularly interact with have become my friends. | ☐ | ☐ | ☐ | ☐ |
| I experience friendliness from other players. | ☐ | ☐ | ☐ | ☐ |
| I had to adjust my actions based on the actions of other players. | ☐ | ☐ | ☐ | ☐ |
| I paid close attention to the actions of other players. | ☐ | ☐ | ☐ | ☐ |
| I felt a sense of closeness to certain characters in the game. | ☐ | ☐ | ☐ | ☐ |
| I formed a bond with some of the characters. | ☐ | ☐ | ☐ | ☐ |

## Section 2

#### Revised computer game attitude scale

| Factors and Items | Strongly Agree | Agree | Disagree | Strongly Disagree |
|---|---|---|---|---|
| *Confidence* | | | | |
| I am good at playing mobile games. | ☐ | ☐ | ☐ | ☐ |
| Playing mobile games comes naturally to me. | ☐ | ☐ | ☐ | ☐ |
| I understand and play mobile games well. | ☐ | ☐ | ☐ | ☐ |
| I am highly skilled at playing mobile games. | ☐ | ☐ | ☐ | ☐ |
| *Learning* | | | | |
| I like taking a course that uses mobile games as a learning tool. | ☐ | ☐ | ☐ | ☐ |
| Utilizing mobile games is an effective method for learning. | ☐ | ☐ | ☐ | ☐ |
| Playing mobile games enhances my hand-eye coordination. | ☐ | ☐ | ☐ | ☐ |
| Mobile games foster the development of my imagination. | ☐ | ☐ | ☐ | ☐ |
| I feel confident in my ability to excel in mobile games. | ☐ | ☐ | ☐ | ☐ |
| *Liking* | | | | |
| I have a positive inclination when people discuss mobile games. | ☐ | ☐ | ☐ | ☐ |
| I experience a sense of ease while playing mobile games. | ☐ | ☐ | ☐ | ☐ |
| I have a strong interest in solving quests in mobile games. | ☐ | ☐ | ☐ | ☐ |
| I consistently strive to complete missions in the mobile game. | ☐ | ☐ | ☐ | ☐ |
| *Leisure* | | | | |
| Playing mobile games makes me happy. | ☐ | ☐ | ☐ | ☐ |
| Playing mobile games is part of my life. | ☐ | ☐ | ☐ | ☐ |
| When I have free time, I play mobile games. | ☐ | ☐ | ☐ | ☐ |
| I talk about mobile games with my friends. | ☐ | ☐ | ☐ | ☐ |
| I am not alone in a mobile game as I can make friends there. | ☐ | ☐ | ☐ | ☐ |

## Section 3: Open-Ended Questions

1. How would you describe your game experience while playing mobile learning games? Choose any game you want to describe and narrate your experience while playing it.
2. Did you like playing mobile chemistry games? Explain why.
3. If you were a developer of a mobile chemistry game, what improvements would you make to the mechanics?
4. Did you learn chemistry concepts while playing mobile chemistry games? Explain why.
5. What features do you expect from a mobile game for chemistry education?

## APPENDIX B. SAMPLE QUOTATIONS FROM OPEN-ENDED QUESTIONS GROUPED ACCORDING TO INSTRUMENTS

### Part 1: Ubisoft Perceived Experience Questionnaire

A. Autonomy
- When playing [game], I usually can predict how to solve the next level because it is very obvious since the only difference between levels is the game background and the enemy. [P63]
- I love puzzles that's why I like [game] but sometimes it gets boring to play because it has only one theme. I would like it very much if I can customize the game based on my needs. [P125]
- I don't usually play adventure games but [game] is a good one because I feel like I'm actually living on the virtual world where I can do anything I want. [P562]
- I always recommend [game] to my friends and classmates because [game] allows you to learn how to be a good decision maker based on the actions you've made in the game. [P603]
- The *[game]* lacks variety in gameplay, which makes the entire experience boring. [P127]

B. Competence
- Back then, I always play [game] before my trigonometry quiz or exam because I can review formulas and how to use it step-by-step to solve problems. [P29]
- When I started playing [game], I almost quit. I thought it was difficult to play. The good thing was, I know some of the answers on the easy level and I got used to the questions. [P53]
- I always enjoy playing [game] before I sleep because it relaxes me when solving puzzles. I am now on level 1052 and it makes me addicted to playing it again and again. [P67]
- Do not play [game] unless you're a science whiz. If you do not have the necessary knowledge, you will not be able to progress in the game. It sucks! [P278]
- I saw my brother playing [game] and I got curious so I downloaded it. Surprisingly, I can actually solve mathematical problems even if I'm not that good in math. [P342]

C. Relatedness
- I think [game] would be better if I can play and compete with other gamers. In my opinion, a little mental competition would motivate me more to study. [P99]
- I feel like I'm a smart person when I'm at the top of the leaderboard. It keeps me motivated to play [game] again and again so that I can retain on the top player spot. [P121]
- I play [game] before so I know in my heart that I will like to play [game] since they are similar online multiplayer adventure game. I like to play and solve quests with other gamers. [P322]
- I'm a shy person that's why I prefer multiplayer games like [game]. I can freely talk to other people without worrying that they will say something bad about me. [P528]
- I was invited by my friends to join in their clan in [game]. It's ridiculous because it's called the 'MathBusters'. But I got to admit, I like it when we play together. [P567]

## Part 2: Revised Computer Game Attitude Scale

A. Confidence
  - The atoms are randomly generated so even if I build my technique and be ready for them, I still lose the game. It's frustrating. It feels like there's no way for me to win even if I store an atom for later use or create a perfectly symmetrical arrangement only. [P311]
  - It's hard to understand the pattern of the game. Maybe I don't like the game, or maybe I just don't like chemistry as a subject but I still prefer to play other games. [P423]
  - At first, I don't understand how to play [game]. But I got used to it after a few plays. Although, it became boring because I only have to do one thing again and again. [P424]
  - If I am the creator of the game, I will put a detailed tutorial on the game so that first time users will be confident in playing a game based from a subject like science. [P528]
  - Personally, I think the game has a potential to be an addicting game like Candy Crush. But it's more difficult to solve the puzzles because I'm not good in Chemistry. [P533]

B. Learning
  - I'm not sure if I actually learned how atoms work. When I combined two circular atoms with the same color, I don't really understand what happened aside from the atoms produce new atom. [P2]
  - I don't think I learned something new by combining two atoms of the same color. As long as it has the same color, I will fuse it even though I don't understand it. [P6]
  - I don't know what to combine in [game]. I just swipe repeatedly until something is combined. Though I learned to combine two hydrogens always as the first step. [P72]
  - I have no prior knowledge in this kind of subject, or maybe I forgot what I learned during elementary. That's why I don't like the game. I can't play it. [P212]
  - I am not familiar with how atom works and fused together. I have no idea about the subject and maybe that's why I don't excel on the game. [P223]

C. Liking
  - Pretty good games, but similar and common game concepts. If I am a game developer and science subject is my theme, I will use asset designs like laboratory with equipment like a microscope or those that are common for students like me, or maybe I have a protagonist character who look like a chemist, or a scientist wearing a lab gown and all. [P31]
  - If this is supposed to teach me the periodic table, I'm not sure if learned something but in my opinion it is the best game I've put on my device in a long time. [P44]
  - I like the game concept of using chemistry. It's unique. I wish the game has an appealing visual design that complements the theme. I think it will be a better game that way. [P136]

D. Leisure
  - For a moment, I like the games. Until it gets boring. I don't think I'll play it again. [P22]
  - I'd rather play other puzzles games that I can actually enjoy. [P56]
  - I usually like puzzles game but not this kind of puzzles. I will not recommend it to someone who do not like science or chemistry. [P255]
  - I played a lot of games so I know giving achievements as a prize on the quest will help to motivate me. But it's missing. It's not good for a long time play. [P565]
  - As an activity in school, I will play it. As part of my daily game? Probably not. Graphics are boring and too simple. If I am to change something, I will add explosion effects with smoke and particles every time the atoms are combined with exciting sound effects. [P569]

## APPENDIX C.

### Characteristics of mobile chemistry games

<table>
<tr><th>Name</th><th>Developer</th><th>Description</th><th>Chemistry Concepts Conveyed</th><th>Remarks</th></tr>
<tr><td>Chemtrix</td><td>Sam Woolf</td><td>An arcade style puzzle game where the goal is to build molecules to progress through the game. There are 24 levels in the game focusing on connecting atoms to form molecules.</td><td>● Molecule formation from free elements<br>● Covalent bond formation</td><td rowspan="4">● No narrative.<br>● Low replayability.<br>● No good balance of challenge and reward<br>● Games do not reflect an accurate chemistry concept because not all molecules could be formed by combining elements from their free state.<br>● Possible misconception of chemistry principles among users.</td></tr>
<tr><td>Molecules</td><td>Rob De Ruiter</td><td>A puzzle game that allows players to earn points by connecting atoms together to get molecules.</td><td>● Molecule formation from free elements<br>● Covalent bond formation</td></tr>
<tr><td>Atomas</td><td>Sirnic</td><td>An incremental puzzle game focusing on fusion of atoms starting from hydrogen. Primary goal is to create the valuable elements like Gold, Platinum, and Silver.</td><td>● Formation of heavy elements from lighter atoms<br>● Concept of matter and anti-matter<br>● Charge neutralization</td></tr>
<tr><td>Chemistry 2048</td><td>Xasaroff</td><td>A sliding block puzzle game based on a popular 2048 game. This focuses on creating substances from individual tiles representing individual elements.</td><td>● Formation of heavy elements<br>● Chemical reactions</td></tr>
</table>

Note: The characteristics mentioned above were derived from the specific version of the game that was available during the research period.

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