

Usability Perceptions on Augmented Reality Based Spectral Crime Analysis Network Game for Sustainable Learning of Ultraviolet-Visible Spectroscopy

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Abstract: The aim of this study was to develop, validate, and evaluate the usability of the Spectral Crime Analysis Network (SCAN) game, an augmented reality game-based learning tool for undergraduate ultraviolet-visible (UV-Vis) spectroscopy. The SCAN game was developed comprising all stages of ADDIE model, used a hybrid augmented reality embedded game-based learning approach and aligned with the learning standards of UV-Vis spectroscopy. This game is developed as a learning and reinforcement tool in analytical chemistry instrumentation for undergraduate chemistry students. This study involved 235 chemistry undergraduate respondents, of which 125 students from Sultan Idris Education University Malaysia, 57 students from Sriwijaya University Indonesia and 53 students from State Islamic University Walisongo Indonesia. It was found that the SCAN game demonstrated high usability with mean scores of 3.49 (SD = 0.489) for usefulness, 3.49 (SD = 0.474) for ease of use, 3.48 (SD = 0.504) for ease of learning and 3.53 (SD = 0.476) for satisfaction. The high satisfaction score (M=3.53) indicates that SCAN game supports cooperative and interactive learning, in line with SDG4's focus on leveraging technology for quality education.

Keywords: Analytical Chemistry; Augmented Reality; Chemistry Education; Game-based Learning; UV-Vis Spectroscopy

Introduction

Education plays a crucial role in a nation's progress, preparing the upcoming generation of citizens to be skilled and well-informed about contemporary studies. In the modern era, education demands a creative and holistic approach to prepare students to adapt to the fast-paced, advancing world. Consequently, the rapid progress in recent years has opened up opportunities for educational innovations that embrace a more student-centred approach by integrating real-world problem-solving and collaborative skills in teaching and learning,

which is more suited to the 21st-century learning ecosystem (Yulianti et al., 2025). These educational innovations could help promote engaging, critical and meaningful learning sessions in the classroom. The Malaysian Education Blueprint (2013-2025) emphasises the significance of advancing Science, Technology, Engineering, and Mathematics (STEM), alongside the integration of Higher Order Thinking Skills (HOTS) in the framework of 21st-century education (Kementerian Pendidikan Malaysia, 2019). Similarly, Indonesia has committed to promoting STEM education through various parties, and working closely United States

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Agency for International Development (USAID) to develop a STEM-based learning model (Permanasari et al., 2021; Hayati et al., 2024).

Chemistry is a discipline that demands strong theoretical and analytical abilities to grasp abstract concepts. A commonly used method in analytical chemistry is UV-Vis light spectroscopy, which uses ultraviolet and visible light to characterise substances through absorbance. Carpentieri & Domenici (2024) indicated that the spectroscopy technique boasts a wide range of applications in analytical chemistry, establishing it as a standard method for examining various substances, solutions, and complex materials. This technique's versatility makes it a crucial topic in chemistry education at Malaysia's tertiary level. However, the abstract nature of UV-Vis spectroscopy concepts, which primarily occur at the subatomic level, often poses challenges for students in terms of comprehension (Daniel Maggioni et. al, 2023; Carpentieri & Domenici, 2024). This is further exacerbated by the overwhelming feeling of learning a complex topic in a classic lecture method hinders students' learning and reduces intrinsic motivation (Chávez Herting et al., 2020; Khobir et al., 2022; Vala et al., 2024).

Several previous chemistry teaching tools have been used as an approach to overcome this issue. One of the methods is by utilising game-based learning that uses a constructive learning model using tools that have integrated academic and game elements in teaching abstract and complex chemistry topics (Olim et al., 2024; Al Ghawail & Yahia, 2025). Isma et al. (2022) indicated that game-based learning engages students through game-playing activities, game content, and problem-solving methods within games, which aim to enhance students' knowledge and skills through challenges or evoking emotions. Hubahib & Mark (2025) have developed a game on forensic chemistry, incorporating a role-playing genre where students engage in role-playing as forensic investigators, examining case evidence that includes toxicology and drug analysis reports, DNA samples, and physical evidence. Similarly, puzzle games are also used in chemistry education, particularly involving laboratory environments, often referred to as escape labs (Bertram et al., 2025; Vergne et al., 2019). Da Silva Júnior et al. (2019), on the other hand, used a competitive tabletop game that incorporates a player-centric achievement design that fosters healthy competition in winning, determined through active problem-solving integrated within the game mechanics.

Thus, a game-based learning approach, especially AR used in the SCAN game is known to address abstraction due to their ability to visualise subatomic phenomena (electron transitions) and simulate sensitive instrumental procedures interactively, as stated by

Domínguez Alfaro et al. (2022). Despite the current teaching tool development, none of them caters for the UV-Vis spectroscopy topic using AR and Near-Field Communication (NFC) integrated tabletop blended game-based learning approach. In response to this gap, this research is conducted based on two research objectives, which are to develop the Spectral Crime Analysis Network (SCAN) game with good validity for chemistry undergraduates in learning UV-Vis spectroscopy and to test the Spectral SCAN game's usability perception in terms of usefulness, ease of use, ease of learning, and satisfaction.

Method

This study closely follows a design and developmental research (DDR) approach, which uses the analysis, design, development, implementation and evaluation (ADDIE) model. This model is chosen primarily due to its structured approach to ensure that the instructional aspect of the SCAN game is carefully designed and evaluated before being implemented.

Analysis

The first step in the ADDIE model is the analysis process, which was done through a need analysis questionnaire conducted among 34 students who have learnt UV-Vis spectroscopy. It was found that 94.1% of the respondents concurred that the subjects related to UV-Vis spectroscopy are complex. In addition to that, the conventional lecture method used by lecturers is often overwhelming for students, as shown by 94.1% of students who felt exhausted learning UV-Vis spectrometry using the conventional PowerPoint lecture method shown in Figure 1.

Do you feel exhausted and bored learning UV-Vis Spectroscopy using the conventional powerpoint lecture method ?

34 responses

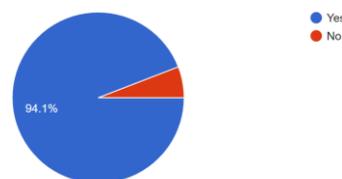


Figure 1. Need analysis result on students' motivation in learning UV-Vis spectroscopy using the conventional PowerPoint lecture method among 34 respondents

When asked about preferred learning methods, 82.4% of students prefer learning UV-Vis spectroscopy through game-based learning (GBL) that incorporates real-world applications (Figure 2). This evidence indicates that game-based learning is a viable alternative to the traditional "chalk and talk" approach that is still being employed in higher education institutions.

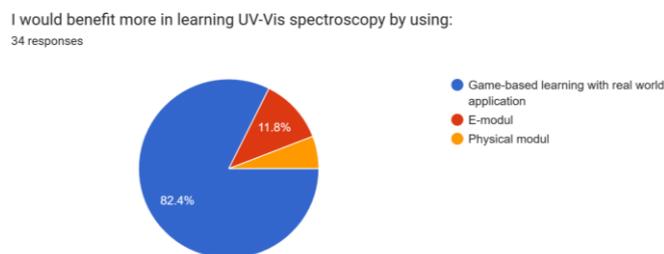


Figure 2. Need analysis result on students' preference for UV-Vis spectroscopy learning method, conducted among 34 respondents

Design and Development

Next, the design phase was a crucial step to lay down the foundations of the SCAN game, built on cognitive learning theories and gamification principles. A cooperative multiplayer role-play genre was designed for the game, allowing an interactive learning experience as shown in Figure 3. The design process of the game incorporates multiple cognitive theories that involve cognitive load theory, schema development and scaffolding. These theories are the fundamental aspect of the SCAN game development, as the sole purpose is to reduce the extraneous cognitive load and ensure the game supports the learning requirements of the UV-Vis spectroscopy concepts. The game theories are also carefully designed to stimulate the analytical thinking process among players.



Figure 3. Role-playing genre used in the SCAN game

The development phase covers the physical development, digital development and augmented reality development. The physical aspect of the game involves the board, manual book, name tags and housing box as shown in Figure 4. The game also features near-field communication (NFC) stickers that are placed on the board, which redirect any device that comes into contact with the board to the URL of each chapter, connecting to the digital aspect of the game.



Figure 4. Overview of the SCAN game's physical elements

The digital components of the games utilise multiple free software and platforms such as Canva and Genially. Genially serves as the assembly platform for the game. Each chapters are designed in its own chapter to allow multiple uniform resource locators (URL) that can be embedded into different NFC stickers on the game board. After uploading the graphics generated by Canva AI, the interactivity is added to the icons to display notes, protocols and other information. Questions are then set with two variations, which are multiple-choice and single-choice questions. Instructions are strategically added into the appropriate part of the game for better coordination and action in the game, as shown in Figure 5.

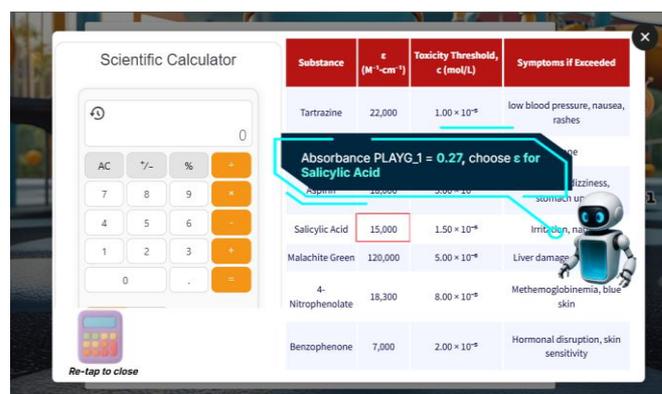


Figure 5. The question development in the SCAN game is equipped with detailed instructions

In addition to that, the game is designed in a chronological order of analysis to allow a step-by-step approach in determining the substances using different protocols. This is done systematically to ensure players do not feel overwhelmed and lost while playing the game. Proper scaffolding is provided using notes,

protocols, help buttons and feedback to allow a positive learning experience (Sun et al., 2023).

The AR component of the game serves as a learning tool to learn the instrumentation aspect of the UV-Vis spectrophotometer. The 3D model is designed using an open-source AI generator called Meshy AI. The AI generator fabricates 3D models in .glb format using prompts or a reference image. The 3D models that were generated for the SCAN game were the UV-Vis spectrophotometer and cuvettes. The 3D models are then assembled in Assembler Studio by integrating animations and trigger actions to create an AR virtual lab simulation (Figure 6). Instructions are also clearly provided on how to conduct calibration and sample analysis in the AR area, along with a diagram of internal components of the UV-Vis spectrophotometer, as shown in Figure 6. This allows a pre-exposure to the components before actually using the instrument in the laboratory, which is limited by time and the number of instruments that are available. Finally, the AR dimension is embedded into a marker. The marker would open up the AR dimension when the players scan the quick response (QR) code that is printed and included in the game box.

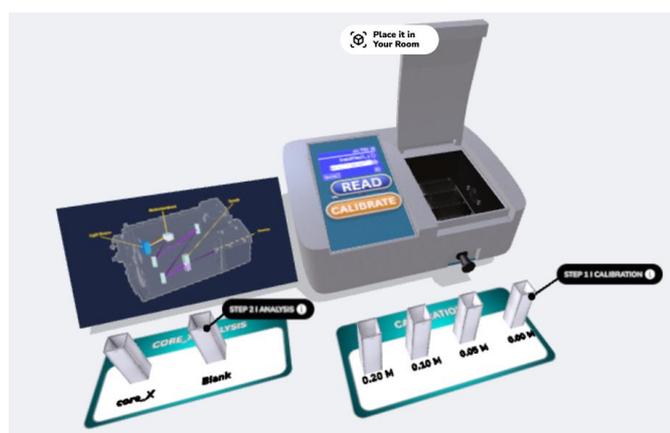


Figure 6. Augmented reality setup in Assembler Studio of UV-Vis spectrometer simulation

Implementation

The implementation phase of the SCAN game is done through a pilot study with 30 students who have learnt UV-Vis spectroscopy. The purpose of this pilot test is to determine the reliability of the SCAN game and the usability perception questionnaire in addressing the research questions. The implementation phase is also done to collect preliminary data on initial qualitative feedback from students regarding gameplay, clarity of instructions, and their engagement before prior to the actual study. In addition, any technical malfunctions and errors that might not have been noticed during the development period is also addressed after the implementation phase.

Evaluation

The evaluation phase is employed a descriptive data analysis to find the mean and standard deviation. These statistical measures were extrapolated to address the research questions by examining if the SCAN game developed for the UV-Vis spectroscopy topic demonstrated a good validity value. In addition, the analysis provides insights on the undergraduate chemistry students' perceptions on the usability perceptions of the SCAN game in terms of usefulness, ease of use, ease of learning, and satisfaction.

Population and sampling

The target population of this research consists of 420 undergraduate students learning UV-Vis spectroscopy from Sultan Idris Education University, Sriwijaya University and State Islamic University Walisongo. The sample is representative of the target population, in which a generalisation can be made to the entire population, given that the sample size obeys the minimum value of 201 respondents proposed by Krejcie and Morgan (1970). A probabilistic simple random sampling technique was used to select 235 undergraduate students learning UV-Vis spectroscopy in their courses. The questionnaire was distributed online through course lecturers of academic institutions and in-person recruitment, and completing the survey was taken as an indication of participants' consent.

Respondents' Demography

The majority of respondents are from Sultan Idris Education University with 125 students (53.19%), followed by Sriwijaya University with 57 students (24.26%) and State Islamic University Walisongo with 53 students (22.55%), as shown in Table 1.

Table 1. Distribution of students based on gender and educational institute

| Educational Institute | Frequency (student) | | Total |
|---|---------------------|-----------------|------------------|
| | Male | Female | |
| Sultan Idris Education University, Malaysia | 31 (13.19%) | 94 (40.00%) | 125 (53.19%) |
| Sriwijaya University, Indonesia | 7 (2.98%) | 50 (21.28%) | 57 (24.26%) |
| State Islamic University Walisongo, Indonesia | 14 (5.96%) | 39 (16.60%) | 53 (22.55%) |
| Total | 52 (22.13%) | 183 (77.80%) | 235 (100.00%) |

In terms of gender, the respondents consist of 183 female students (77.80%) and 52 male students (22.13%). According to Álvarez-Herrero & Valls-Bautista (2021),

there was no significant difference between genders in students' preferences for a game-based learning approach. Thus, the gender distribution is analysed for descriptive purposes and does not affect the results of the study.

Research instrument

The Spectral Crime Analysis Network (SCAN) game usability perception questionnaire used in this study was adapted from Lund (2001), which comprises four constructs: usefulness, ease of use, ease of learning and satisfaction. The construct for the SCAN game is based on the USE questionnaire proposed by Lund (2001), adapted from Davis (1989), which contains 30 items randomly distributed in four constructs to measure usability perception. The questionnaire uses a four-point Likert scale to indicate respondents' degree of agreement towards the usability perceptions of the SCAN game. A four-point Likert scale was chosen to eliminate a neutral perception to avoid midpoint bias and force respondents to express a clear preference for the SCAN game's usability.

Face, content and construct validity

In the validation process of the SCAN game, the validity evaluation form consists of two sections, covering face and content validity of the SCAN game. The face validity of the SCAN game provides a surface validation of the physical appearance of the research instrument and product, ensuring it is sufficient to accommodate the required use. Meanwhile, the content validity refers to whether an instrument encompasses all the essential elements necessary to cover a specific aspect of cognition or impairment in a particular context, taking into account practical considerations and other factors to ensure the accuracy and completeness of the assessment (Stout et al., 2017). The construct validity was conducted for 30 items within the four main constructs, namely usefulness, ease of use, ease of learning and satisfaction to represent usability perception. The face and content validity of the SCAN game and the construct validity of the usability perception questionnaire is computed through expert validity percentage, which was evaluated by four experts from Sultan Idris Education University, Sriwijaya University, Sebelas Maret University and Yogyakarta State University, as shown in Table 2. The face, content and construct validity shows a high validity score, which exceeds the 70% minimum validity percentage, postulating a strong validation to assess the usability perception of the SCAN game as a learning kit for the UV-Vis spectroscopy topic (Mohd Noah & Ahmad, 2005).

Table 2. Expert agreement percentage on face, content and construct validity of SCAN game and usability perception questionnaire

| Expert | SCAN Game | | Usability Perception Questionnaire |
|----------|---------------|------------------|------------------------------------|
| | Face validity | Content validity | Construct validity |
| Expert 1 | 100.00% | 100.00% | 99.20% |
| Expert 2 | 100.00% | 100.00% | 100.00% |
| Expert 3 | 98.00% | 99.70% | 97.50% |
| Expert 4 | 90.00% | 95.00% | 98.70% |

Research Reliability

In addition to the validity test, a non-cognitive measured reliability test that tests for internal consistency was carried out through a pilot study among 30 chemistry undergraduate students of Sultan Idris Education University. According to Gani et al. (2020), a small-scale pilot test satisfies the requirement for validity and reliability of a research instrument. The Cronbach's Alpha value obtained from the validity test was 0.971, which postulates an excellent reliability of internal consistency in the usability perception questionnaire. This shows that the items are correlated and consistent in measuring the usability perception when compared to previous game-based learning approaches in chemistry education (Li et al., 2022; Najib & Karpudewan, 2024).

Results and Discussion

The data analysis is conducted in accordance with the second research question, "What are undergraduate chemistry students' perceptions of the usability of the Spectral Crime Analysis Network (SCAN) game in terms of usefulness, ease of use, ease of learning, and satisfaction?" These data were then processed through a descriptive statistical analysis to find the mean and standard deviation for the four main constructs that represent usability perception.

Usefulness

The usefulness construct measures the capacity of the SCAN game as a learning tool for the UV-Vis spectroscopy topic in Instrumentation in Analytical Chemistry. According to Davis (1989), usefulness is defined as the extent to which an individual thinks that utilising a specific system improved their effectiveness at work. In the context of the SCAN game, it reflects the degree to which students feel that playing the game improves their comprehension and application of the intended educational content, sharpens their problem-solving abilities, and meaningfully supports their learning objectives.

Table 3. Distribution of agreement scale on the SCAN game usefulness (U) construct

| Item | Description | Frequency | | | | Mean value | Standard Deviation |
|---------------|--|--------------|---------------|-----------------|-----------------|------------|--------------------|
| | | 1 | 2 | 3 | 4 | | |
| U1 | The SCAN game helps me to learn UV-Vis spectroscopy more effectively. | 2 (0.90%) | 3 (1.30%) | 97 (41.30%) | 133 (56.60%) | 3.54 | 0.572 |
| U2 | The SCAN game helps me be more productive in learning UV-Vis spectroscopy. | 1 (0.40%) | 4 (1.70%) | 105 (44.70%) | 125 (53.20%) | 3.51 | 0.558 |
| U3 | The SCAN game is useful as a reinforcement tool in learning UV-Vis spectroscopy | 2 (0.90%) | 1 (0.40%) | 93 (39.60%) | 139 (59.10%) | 3.57 | 0.553 |
| U4 | The SCAN game gives me more control over the concepts that need to be learnt in UV-Vis spectroscopy. | 2 (0.90%) | 5 (2.10%) | 110 (46.80%) | 118 (50.20%) | 3.46 | 0.586 |
| U5 | The SCAN game helps me reach the learning objectives in UV-Vis spectroscopy. | 2 (0.90%) | 7 (3.00%) | 97 (41.30%) | 129 (54.90%) | 3.50 | 0.602 |
| U6 | The SCAN game saves me time in learning UV-Vis spectroscopy. | 1 (0.40%) | 8 (3.40%) | 98 (41.70%) | 128 (54.50%) | 3.50 | 0.587 |
| U7 | The SCAN game meets my needs. | 2 (0.90%) | 10 (4.30%) | 110 (46.80%) | 113 (48.10%) | 3.42 | 0.618 |
| U8 | The SCAN game has everything I would expect it to have. | 3 (1.30%) | 12 (5.10%) | 99 (42.10%) | 121 (51.50%) | 3.44 | 0.653 |
| Total Average | | | | | | 3.49 | 0.489 |

Item U3 of the usefulness constructs highlights that the SCAN game was a useful post-lecture learning tool, which increases its potential as a reinforcement tool (Table 3). This aligns with the view of Sulma Paola Vera-Monroy et al. (2024), where game-based learning could act as a self-paced reinforcement tool that improves learning by applying theories to real-life situations. This is also shown by Item U4, which indicates that respondents agree that they have control over the concepts learnt in UV-Vis spectroscopy while using the game (M = 3.68, SD = 0.491). These findings show that the self-paced learning offered by SCAN game involving concepts with high intrinsic load may promote gradual schema development, making it more manageable for students to process (Shifflett, 2022).

Based on Table 3, Students' perception of the usefulness of the SCAN game was highly positive, with a total average mean score of 3.49 and 0.489. According to Toomnan & Putsayainunt (2022), the respondents' average mean value postulates that the respondents agree that the SCAN game is useful as a learning tool for

learning UV-Vis spectroscopy. Thus, the data indicate that students find the SCAN game facilitates comprehension and supports their learning objectives. These findings are in line with the views from Sampath Kumar (2023), where game-based learning approaches could improve rational thinking, improve chemistry instruction, raise student engagement and achieve learning outcomes. Similarly, in the study of Mao et al. (2021), game-based learning has a high potential to stimulate critical thinking through role-playing games, such as the SCAN game.

Ease of Use

The ease of use (EU) refers to the degree to which a person believes that using a particular system would be free of effort (Davis, 1989). In the context of the SCAN game, ease of use is operationally defined as the ability of students to navigate, interact, and complete tasks within the SCAN game, using instructions and game mechanics effortlessly. The ease of use reflects the intricacy level of the game design and clarity of the

instructions and feedback to guide students in the game environment.

From Table 4, items EU1 and EU6 show that students strongly agree the SCAN game is easy to use and does not require excessive effort indicated by mean score of 3.55. This is crucial to ensure that the students are not overwhelmed when using the game which would increase extraneous cognitive load caused by poor representation of the learning content during the learning process (Chen et al., 2023). Next, the findings on item EU2 and EU3 suggests that respondents agree on the simplistic design and user-friendly learning experience. This is because of the careful consideration of students' experience during the SCAN gameplay, which is designed using a simple and user-friendly approach to boost student motivation during gameplay with a balanced game mechanics and objectives, in line with the views of Zamri & Tan (2022).

In addition, item EU4 and postulates shows students agree that it requires fewest steps possible to accomplish the learning objectives. This aspect is important as minimal steps during gameplay tasks reduces students' effort to reach learning objectives. Additionally, findings on EU5 and EU8 shows students strongly agree that the SCAN game provides a flexible approach in learning UV-Vis spectroscopy and a consistent design throughout the gameplay with a mean score of 3.53 and 3.54 respectively. This means that the flexibility on the SCAN game information visualization interfaces prioritizes fluid and offer adaptive interactions for different students, mental capabilities and maintain uniform design standards to simplify learning curves among students, supported by Liu & Yang (2025).

Item EU7 in the other hand depicts agreement on the usability of SCAN game without written instructions ($M = 3.34$, $SD = 0.674$). This is because the SCAN game integrates tutorials and instruction during gameplay for easier recall and navigation for students in completing tasks in order to achieve the expected learning objectives. This item also has a relatively large number of respondents who disagree on using the SCAN game without written instructions, as games usually have these guidelines printed for quick reference. Although the average score indicates agreement, EU7 has the lowest score and the highest dispersion, suggesting that the integrated instruction feature may not completely replace the need for accessible written guidance, which may impact the experience for minority of users.

In relation to ease of use, item EU9 and EU11 has a good agreement among respondents on the occasional and regular usage, as well as using the SCAN game

successfully every time. This is because students find that they are willing to use the game on occasional and regular uses as a reinforcement tool in learning UV-Vis spectroscopy concepts that involves multiple abstract components. This is supported by Daniel Maggioni et. al (2023), the abstract principles underlying UV-Vis spectroscopy that occur at subatomic level can be hard for students to visualise and understand. Thus, a game-based learning environment could help students learn in a fun learning environment. Moreover, the SCAN game is well-designed as an educational game that offers successful achievement of learning objectives as the players are well guided through the core mechanics of the game, providing a sense of satisfaction after completing each task.

Last but not least, the findings on item EU10 shows that students agree that they can recover quickly from mistakes during gameplay ($M = 3.43$, $SD = 0.605$). This is due to the fact that the SCAN game has error prevention features that offer unlimited chances for students to retry wrong answers before moving on to the next mission. This is in line with the views of Zammit et al. (2022), students show a higher accuracy after each trial and immediately fix misconceptions, that may promote better understanding of the theoretical concepts of UV-Vis spectroscopy.

Based on Table 4, the ease of use construct has an average mean of 3.49, which indicates that the majority of the students agree that the SCAN game is easy to use (Toomnan & Putsayainunt, 2022). The mean score indicates that the SCAN game is easy to use by students in learning UV-Vis spectroscopy. It shows that students can use the game and follow the game mechanics with minimal errors. Similarly, in the findings of Li et al. (2022), who stated that students who found a chemistry learning tool easy to use believed that it could help them understand the theoretical concepts, and the rules of the game were simple and easy to understand. According to Mustapha (1999), the dispersion of responses is at a medium range of consensus ($SD = 0.525$) due to items EU2 ($M = 3.45$, $SD = 0.654$), EU4 ($M = 3.43$, $SD = 0.640$) and EU7 ($M = 3.34$, $SD = 0.674$). This is largely caused by the relatively high number of respondents who disagree with the items. A minority of respondents find the SCAN game not simple and require more steps to achieve the learning objectives, which might be due to the complex protocols to find wavelength, computing toxicity, identifying electronic transitions and spectral shifts. Hence, it is important to evaluate the ease of use construct within the usability perception of the SCAN game to ensure a good student experience when using the game as a learning tool for UV-Vis spectroscopy.

Table 4. Distribution of agreement scale on the SCAN game ease of use (EU) construct

| Item | Description | Frequency | | | | Mean value | Standard Deviation |
|---------------|---|--------------|----------------|-----------------|-----------------|------------|--------------------|
| | | 1 | 2 | 3 | 4 | | |
| EU1 | The SCAN game is easy to use. | 0 (0.00%) | 5 (2.10%) | 96 (40.90%) | 134 (57.00%) | 3.55 | 0.540 |
| EU2 | The SCAN game design is simple. | 2 (0.90%) | 15 (6.40%) | 94 (40.00%) | 124 (52.80%) | 3.45 | 0.654 |
| EU3 | The SCAN game is user friendly. | 0 (0.00%) | 6 (2.60%) | 96 (40.90%) | 133 (56.60%) | 3.54 | 0.548 |
| EU4 | The SCAN game requires the fewest steps possible to accomplish the learning objectives. | 1 (0.40%) | 16 (6.80%) | 98 (41.70%) | 120 (51.10%) | 3.43 | 0.640 |
| EU5 | The SCAN game provides a flexible approach to learn UV-Vis spectroscopy. | 0 (0.00%) | 9 (3.80%) | 93 (39.60%) | 133 (56.60%) | 3.53 | 0.572 |
| EU6 | Using the SCAN game does not require excessive effort | 1 (0.40%) | 5 (2.10%) | 93 (39.60%) | 136 (57.90%) | 3.55 | 0.563 |
| EU7 | The SCAN game can be used without written instructions. | 0 (0.00%) | 27 (11.50%) | 102 (43.40%) | 106 (45.10%) | 3.34 | 0.674 |
| EU8 | The SCAN game design is consistent. | 1 (0.40%) | 6 (2.60%) | 92 (39.10%) | 136 (57.90%) | 3.54 | 0.571 |
| EU9 | The SCAN game would interest occasional and regular users. | 0 (0.00%) | 8 (3.40%) | 101 (43.00%) | 126 (53.60%) | 3.50 | 0.565 |
| EU10 | I can recover from mistakes quickly while playing the SCAN game. | 1 (0.40%) | 11 (4.70%) | 108 (46.00%) | 115 (48.90%) | 3.43 | 0.605 |
| EU11 | I can use the SCAN game successfully every time. | 1 (0.40%) | 9 (3.80%) | 98 (41.70%) | 127 (54.00%) | 3.49 | 0.595 |
| Total Average | | | | | | 3.49 | 0.474 |

Ease of Learning

The ease of learning (EL) is defined as the learning process of users to explore and use the interface within a time period (Lakman & Mokhtar, 2025). In this study, ease of learning explains the duration and independence of students to learn the SCAN game mechanics, understand its rules, objectives, and advance through different levels without prior exposure.

The SCAN game can be learnt quickly without prior exposure, and students can learn the mechanics of the game in a short period of time. This is highly due to the fact that the instructions embedded in the SCAN game use a step-by-step approach with a strategic placement of support in completing each task. This relates to the scaffolding theory of providing assistance to students

until students are able to complete tasks independently (Sun et al., 2023). This is supported by Sani & Ratri (2024), gamified units arranged in a pathway, feedback and structured instructions in digital interfaces offer a direct and efficient approach for quick learning. Item EL3 posits that the SCAN game does not impose a high effort to understand the operational steps during gameplay. This is important to ensure players stay engaged during gameplay. In line with the views of Halim et al. (2021), the learnability reflects the ability of respondents to understand, look for specific information and identify navigational features within a digital interface.

Based on Table 5, the overall ease of learning construct shows that most respondents agree on the ease

of learning the SCAN game, with an average of 3.48. The standard deviation is 0.504, which is within the low range, implying that most respondents are in consensus with the mean. This suggests that the SCAN game is easy to operate and learn with minimal effort because of the strategically developed navigation features and iterative steps in protocols, which may allow users to feel engaged and improve memorability of the game mechanics (Annamalai & Mohamed Faisal, 2023). This is

further supported by Prasetyo & Dewanto (2024) and Ariffin et al. (2022), who stated that a high ease of learning indicates that respondents have high potential to adapt, using a product quickly and easily remember how to use the product. This aligns with the purpose of the ease of learning construct, which is aimed at gaining knowledge easily through a step-by-step approach and improving learning attitudes (Lin, 2022).

Table 5. Distribution of agreement scale on the SCAN game ease of learning (EL) construct

| Item | Description | Frequency | | | | Mean value | Standard Deviation |
|---------------|---|--------------|--------------|-----------------|-----------------|------------|--------------------|
| | | 1 | 2 | 3 | 4 | | |
| EL1 | I learned to use the SCAN game quickly | 0 (0.00%) | 6 (2.60%) | 111 (47.20%) | 118 (50.20%) | 3.48 | 0.549 |
| EL2 | I easily remember how to use the SCAN game | 1 (0.40%) | 8 (3.40%) | 109 (46.40%) | 117 (49.80%) | 3.46 | 0.586 |
| EL3 | The SCAN gameplay is easy to learn | 1 (0.40%) | 6 (2.60%) | 98 (41.70%) | 130 (55.30%) | 3.52 | 0.572 |
| EL4 | I quickly became skillful in using the SCAN game. | 2 (0.90%) | 6 (2.60%) | 107 (45.50%) | 120 (51.10%) | 3.47 | 0.594 |
| Total Average | | | | | | 3.48 | 0.504 |

Satisfaction

Satisfaction (S) is defined as the feeling, views or attitude of a person who receives a service and receives feedback that meets expectations or exceeds their expectations (Kamtan & Saengchan, 2024). In the context of SCAN game development, the post-experience enjoyment, positive feelings, and fulfilment of the SCAN game reflect satisfaction, especially in achieving educational value and engagement.

Firstly, the satisfaction construct postulates that respondents strongly agree on the satisfaction (S1) and find the SCAN game is fun to use (S3), with a mean score of 3.77 (SD = 0.561) and 3.57 (SD = 0.545) (Table 6). The strong satisfaction shows that respondents enjoyed the process of using the SCAN game, with most of the features and game elements fulfilling their needs to learn UV-Vis spectroscopy. This is in line with the findings of Yadav & Oyelere (2020), who reported that students find fun learning during game-based learning which corresponds to a high level of learning satisfaction. This may lead to an increase in motivation among respondents to the extent of recommending it to other individuals, in line with the findings in a review that evaluated the value of gamification in higher education science students (Arruzza & Chau, 2021).

Item S4 and S5 suggest that respondents had a wonderful learning experience while completing the

tasks, learning and exploring the concepts of UV-Vis spectroscopy, which directly affects their intrinsic motivation to continue learning. After a sense of uncertainty while exploring the game, respondents also felt the SCAN game worked as they had expected, which corresponds to a good perception on the correlation of the SCAN game features with the current trends of game-based learning, which is supported by San Gabriel & Manalastas (2025).

Overall, the satisfaction construct has a strong degree of agreement with an average mean score of 3.53 (Toomnan & Putsayainunt, 2022). The average dispersion of responses across seven items is reported to be at 0.476, which is within the lower range (Ramlee Mustapha, 1999), as shown in Table 6. From these findings, it shows that the SCAN game has a good satisfaction level among respondents. This proves that game-based learning may boost learning motivation among students as compared to the conventional lecture method used by lecturers. According to Borit and Stangvaltaite-Mouhat (2020), the motivation of being in class is highly correlated with increased classroom interactivity, focus and the perception that the game helped boost learning. This is supported by Aliyu & Talib (2022), who also stated that satisfaction in game-based learning has a high potential to enhance students' engagement, concentration, motivation, and interest.

Thus, this would correspond to a satisfied perception on the learning experience in relation to UV-Vis spectroscopy when using the SCAN game

Table 6. Distribution of agreement scale on the SCAN game satisfaction construct

| Item | Description | Frequency | | | | Mean value | Standard Deviation |
|---------------|--|--------------|---------------|-----------------|-----------------|------------|--------------------|
| | | 1 | 2 | 3 | 4 | | |
| S1 | I am satisfied with the SCAN game | 1 (0.40%) | 5 (2.10%) | 89 (37.90%) | 140 (59.60%) | 3.57 | 0.561 |
| S2 | I would recommend the SCAN game to a friend | 0 (0.00%) | 6 (2.60%) | 91 (38.70%) | 138 (58.70%) | 3.56 | 0.546 |
| S3 | The SCAN game is fun to use. | 1 (0.40%) | 3 (1.30%) | 92 (39.10%) | 139 (59.10%) | 3.57 | 0.545 |
| S4 | The SCAN game works the way I want it to work. | 0 (0.00%) | 8 (3.40%) | 105 (44.70%) | 122 (51.90%) | 3.49 | 0.565 |
| S5 | The SCAN game is wonderful. | 1 (0.40%) | 4 (1.70%) | 98 (41.70%) | 132 (56.20%) | 3.54 | 0.556 |
| S6 | I feel I need to have the SCAN game. | 0 (0.00%) | 12 (5.10%) | 102 (43.40%) | 121 (51.50%) | 3.46 | 0.594 |
| S7 | The SCAN game is pleasant to use. | 1 (0.40%) | 5 (2.10%) | 91 (38.70%) | 138 (58.70%) | 3.56 | 0.562 |
| Total Average | | | | | | 3.53 | 0.476 |

Conclusion

The development of the SCAN game was conducted to facilitate students in learning the UV-Vis spectroscopy topic in analytical chemistry instrumentation. The SCAN game uses a hybrid augmented reality embedded game-based learning approach as a learning kit to tackle the abstract and technical aspects of the UV-Vis spectroscopy concepts. In conclusion, the research objectives to develop the SCAN game with good validity for chemistry undergraduates in learning UV-Vis spectroscopy, and to test the usability perceptions of the SCAN game usability perception in terms of usefulness, ease of use, ease of learning, and satisfaction are satisfied. Overall, the SCAN game has a good usability perception among students, which provides adequate support for the usefulness of the SCAN game for learning UV-Vis spectroscopy. Hence, it is recommended to conduct an effectiveness study involving treatment and control groups to ensure the SCAN game has a strong impact on the students. The SCAN game has a high chance of advancement as an interactive and analytical learning tool in learning UV-Vis spectroscopy. In conclusion, the SCAN game provides an alternative to the conventional

learning method, with enhanced interactivity which not only boosts intrinsic motivation but also supports learning and real-life application in solving issues in different disciplines in support of the Sustainable Development Goals.

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Author Contributions

Conceptualisation-methodology-development, A.A.I.H and A.K.; survey-data curation, A.A.I.H, F.I.S. and L.K.H.; instrument development and validation, S.S., W.A. and A.S. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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