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User-Friendly Evaluation of Three-Dimensional Visualization of Atomic Models on Mobile Teaching Module Application: PyLo-AR

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Abstract

Integrating augmented reality technology in physics education provides students with a novel learning experience, requiring proficient skills and effective organization. PyLo-AR, a Marker-Based Augmented Reality (M-AR) mobile app, teaches atomic models (Dalton, Thomson, Rutherford, Bohr). This study assesses PyLo-AR's user-friendliness using SUS and UEQ methods, involving highschool students. SUS scores indicate a satisfactory usability level (71). UEQ averages are 1.797 (Attractiveness), 1.700 (Perspicuity), 1.577 (Efficiency), 1.605 (Dependability), 1.941 (Stimulation), and 1.067 (Novelty). The category of the stimulation indicator is excellent, which means the PyLo-AR application is highly engaging for learners. The attractiveness, efficiency, and accuracy indicators are rated as "good," indicating that the PyLo-AR application is enjoyable and reliable in understanding the characteristics of each atom model through its 3D visualization features. Meanwhile, the clarity and novelty indicator categories are rated as "above average," suggesting that the PyLo-AR application is sufficiently efficient and easy to understand with an organized User Interface (UI). Thus, the PyLo-AR application has met the criteria for being a user-friendly application for learners to comprehend the characteristics of each atom model.

Keywords: augmented reality, atomic model, SUS, UEQ

INTRODUCTION

The current educational system has entered the era of 21st-century learning. The framework of 21st-century learning requires the integration of technological elements into the learning process that emphasizes Creativity, Critical Thinking, Communication, and Collaboration (Cheng, 2017), as well as a student-centred learning system (Bernard, Borokhovski, Schmid, Waddington, & Pickup, 2017). In line with the modernization of the educational system and the development of digitalization in Indonesia, efforts have been made to support this learning system. As a result, there has been significant growth in ICT (Information and Communication Technology), as indicated by data from the Indonesian Central Statistics Agency (BPS). Over the past five years, the use of ICT in Indonesia has shown rapid progress. This is evident in the internet usage rate, which has reached 78.18 percent. The growth in internet usage is also accompanied by the population using mobile phones, reaching 62.84 percent in 2020 (Sutarsih, Apresziyanti, Wulandari, & Hasyyati, 2020). Based on this data, the utilization

of telecommunications media and platforms that support 21st-century learning has become a prominent area of research, particularly in the field of educational technology in the last five years (Amornkitpinyo & Piriyasurawong, 2017; Gürsoy, 2021; Halimi & Bouchelaghem, 2019).

One of the educational technology products that we have developed is PyLo-AR (Physics Learning of Augmented Reality). PyLo-AR is a mobile application, an augmented reality-based instructional module developed using an empathetic approach toward learners, also known as the design thinking method. The content currently included in the PyLo-AR application covers atomic models, encompassing four atomic models: the Dalton atomic model, J. J. Thomson's atomic model, the Ruther-ford atomic model, and the Bohr atomic model. The PyLo-AR application system was developed using CorelDraw 2021, Blender 3.0, Unity 2020.3.30f1, and the Android Software Development Kit (SDK).

The integration of AR technology in the learning process has been proven to have positive effects on teaching and learning (Tekedere & Göker, 2016; Volioti et al., 2022; Wibowo, 2023), enabling students to engage with captivating learning tools and authentic learning environments (Kovalenko, Marienko, & Sukhikh, 2021; Kustijono & Rahman Hakim, 2014), leading to an enhancement in students' knowledge and understanding of scientific concepts due to the visualization capabilities of Augmented Reality (AR) (Yoon, Anderson, Lin, & Elinich, 2017). However, despite AR technology's benefits, challenges are still associated with its development. A significant challenge in integrating AR technology into the learning process is how students interact with virtual objects within the real physical space, which might require adjustments and training (Lai & Cheong, 2022).

New users might face difficulties using AR applications or devices effectively and determining the best way to deliver specific teaching content through AR technology (Fearn & Hook, 2023; Rabbi & Ullah, 2013). This issue is closely related to user interaction, particularly in the case of the previously developed PyLo-AR application. The interaction of users/students with the PyLo-AR application is a subject that will be investigated to ascertain the user-friendliness of the PyLo-AR application.

METHODS

This research is a quantitative-descriptive study aimed at assessing the user-friendly attributes of the PyLo-AR application through a quantitative approach and descriptive interpretation of the analysis results. The study was conducted at

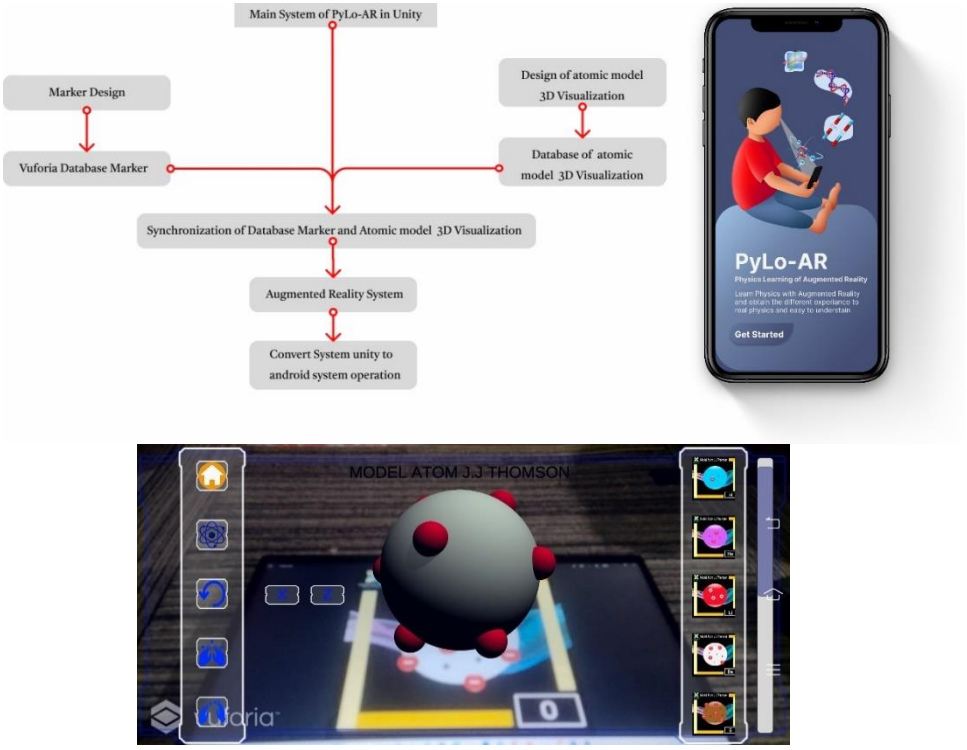

Figure 1. PyLo-AR application AR system design scheme and 3D Visualization system

SMAN 4 Makassar, with 55 students as respondents. Data collection was carried out using survey techniques, and the research instruments employed were the System Usability Scale (SUS) and the User Experience Questionnaire (UEQ). Here is the link to the PyLo-AR application (https://drive.google.com/drive/folders/1obnJQXn1Nz1O1YOFAVeHWv9_3KAK-b0J?usp=drive_link).

1. System Usability Scale (SUS)

The System Usability Scale is a measuring tool utilized to assess the usability of a product or service (Pradini et al., 2019) with a validity ranging from 0.7 to 0.9 (Brooke, 1986). In this study, the SUS is employed to gauge the ease of use of PyLo-AR. The analysis of the SUS scores is conducted using the avarage score equation, $\bar{x} = \frac{\sum x}{n}$.

In analyzing the data from the SUS questionnaire, several rules must be followed for each of the ten questions. The following are the rules to be followed during the scoring calculation in the SUS analysis (Brooke, 1995; Setiawan & Rafianto, 2020):

a) For every odd-numbered question, the final score results from subtracting one from the user's score (x).
b) For every even-numbered question, the final score is obtained by subtracting the user's score (x) from 5.
c) The weighting of the SUS scores is derived from the sum of all user scores multiplied by 2.5.

The interpretation of questionnaire data obtained through the SUS analysis results in 5 levels of descriptors, each depicting the level of ease of use of the PyLo-AR application. The predict table proposed by Derisma (2020) displayed in Table 1.

Table 1. SUS analysis value

SUS Score	Value	Description
Above 80.3	A	Very Good
Between 68 and 80.3	B	Good
68	C	Fair
Between 51 and 67	D	Poor
Below 51	F	Very Poor

2. User Experience Questionnaire (UEQ)

The User Experience Questionnaire (UEQ) is a research instrument utilized for processing survey data related to user experiences to assess the subjective quality assessment of users (Laugwitz, Held, & Schreep, 2008; Schrepp, Hinderks, & Thomaschewski, 2017). The User Experience Questionnaire (UEQ) comprises 26 items based on six aspects of user experience (Wijaya, Santika, Iswara, & Arsana, 2021), namely attractiveness, clarity, efficiency, reliability, stimulation, and novelty (Laugwitz et al., 2008). The analysis of UEQ data employs the Data Analysis Tool, a UEQ calculating tool that can be downloaded from the official UEQ website. In this process, the questionnaire data is input into the "Data" tab of UEQ_Data_Analysis_Tool, and then the weight of each answer can be entered into the "Data" tab of UEQ_Compare_Products (Juniantari, Nyoman, & Putra, 2021). The interpretation of each benchmark range as suggested by Schrepp et al., (2017) is shown in Table 2.

Table 2. UEQ score comparison system

Scale	Lower Border	Bad	Below Average	Above Average	Good	Excellent
Attractiveness	-1	0.69	1.18	1.58	1.84	2.50
Perspicuity	-1	0.72	1.20	1.73	2.00	2.50
Efficiency	-1	0.60	1.05	1.50	1.88	2.50
Dependability	-1	0.78	1.14	1.48	1.70	2.50
Stimulation	-1	0.50	1.00	1.35	1.70	2.50
Novelty	-1	0.16	0.70	1.12	1.60	2.50

a) Very Good: falls within the top 10% range of products with the highest scores.
b) Good: 10% of the products in the dataset have higher scores, while the remaining 75% have lower scores.

c) Above Average: 25% of the products in the dataset have higher scores, while the other 50% have lower scores.
d) Below Average: 50% of the products in the dataset have higher scores, while the remaining 25% have lower scores.
e) Poor: falls within the bottom 25% range of products with the lowest scores.

In this study, the UEQ addresses research questions concerning user-friendliness with the designed product. Measuring the user-friendliness of the PyLo-AR application using the UEQ instrument has been theoretically confirmed to be valid and reliable.

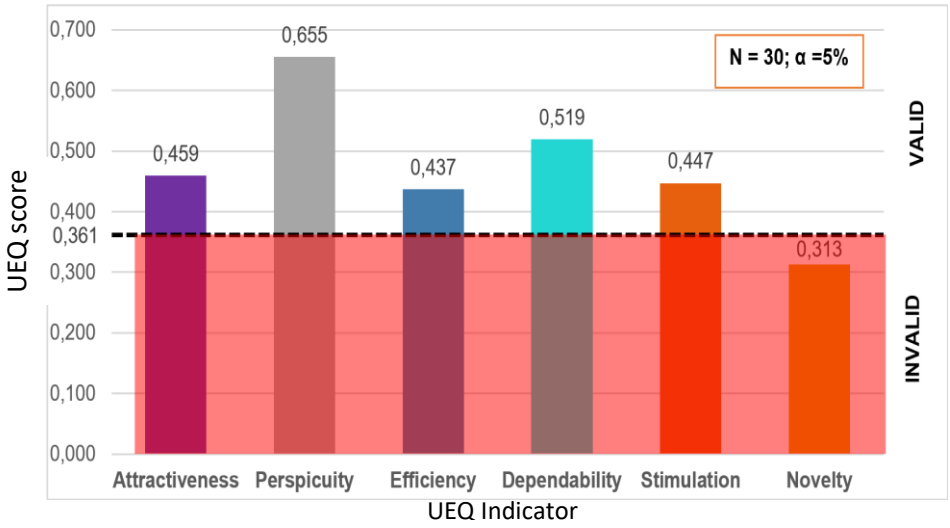

Figure 2. UEQ score comparison system

The theoretical validity and reliability are 0.75 and 0.95, respectively (Laugwitz et al., 2008). However, the UEQ instrument was still empirically tested before its utilization. The empirical testing of the UEQ instrument was conducted due to differences in the population and purpose for which the UEQ instrument was used. This empirical testing involved 30 samples or participants from the 12th-grade science class at SMAN 4 Makassar.

1) Validity

The empirical validity of the UEQ instrument was assessed using the Corrected Item Total Correlation technique to determine the correlation between items within each indicator and the total correlation for each indicator. correlation coefficient testing for the inter-item correlation can be observed in Figure 2, indicating that each UEQ indicator is generally valid, except for the novelty indicator, which shows r count < r table value with a value of 0.313 < 0.361.

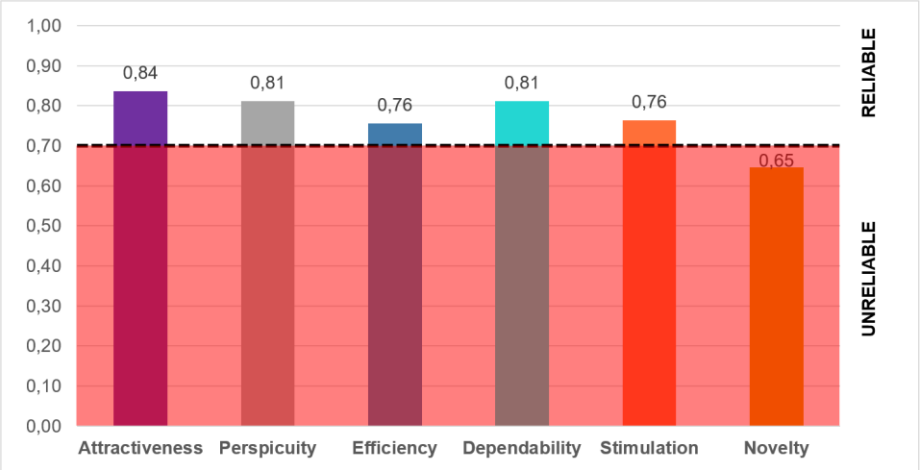

Figure 3. UEQ reliability bar chart

2) Reliability

The results of the reliability testing of the UEQ instrument in Figure 3 indicate that the attractiveness, clarity, efficiency, reliability, and stimulation indicators are reliable or consistent, as the Cronbach's alpha coefficient scores are > 0.70. However, the novelty indicator is not reliable, as its Cronbach's alpha coefficient score is < 0.70 (Cronbach, 1951).

Based on the empirical validity and reliability testing of the UEQ instrument, the novelty indicator of the UEQ shows values that are neither valid nor reliable. This is due to unexpected student responses or the occurrence of the Spurious Overlap Effect from student responses (Hendryadi, 2021). This spurious overlap effect is an overestimate of the correlation between item 26 of the UEQ instrument, which shows correlation scores between items (3,26), (10,26), and (15,26) that are not valid. This results from the empirical pilot sample, which had previously used AR technology for gaming and extracurricular activities, as evidenced by qualitative data from one of the student personas who had prior experience using and creating an AR-based application. Consequently, item 26 of the novelty indicator in the UEQ instrument becomes biased compared to other items within the novelty indicator. Based on this, item 26 of the novelty indicator in the UEQ instrument was not used in the user-friendly testing process.

RESULT AND DISCUSSION

1. Result

a) System Usability Scale (SUS)

SUS is a measurement used to quickly assess the usability of the PyLo-AR application from a user's perspective (Brooke, 1986). The score obtained from the SUS testing of the PyLo-AR application with 55 student respondents is 71.

Based on the average score from the SUS testing of the PyLo-AR application, the PyLo-AR application falls into category B (good). It is considered acceptable or usable for the learning process from the student's perspective (Derisma, 2020).

b) User Experience Questionnaire (UEQ)

The User Experience Questionnaire (UEQ) was analyzed using the UEQ_Data_Analysis_Tool. The analysis of the UEQ yielded several parameters for each of the six UEQ indicators: attractiveness, clarity, efficiency, reliability, stimulation, and novelty (Laugwitz et al., 2008). The results of the descriptive analysis for each UEQ indicator are based on 55 samples. In this table, the UEQ indicator with the highest mean is Stimulation at 1.941, while the lowest is Novelty at 1.067. Below is the graph depicting the results of the descriptive analysis for each UEQ item and indicator.

Table 3. General description of each UEQ indicator

UEQ Indicator	Mean	Variance	Std. Dev.
Attractiveness	1.797	0.659	0.812
Perspicuity	1.700	1.084	1.041
Efficiency	1.577	0.870	0.933
Dependability	1.605	0.728	0.853
Stimulation	1.941	0.722	0.850
Novelty	1.067	1.339	1.157

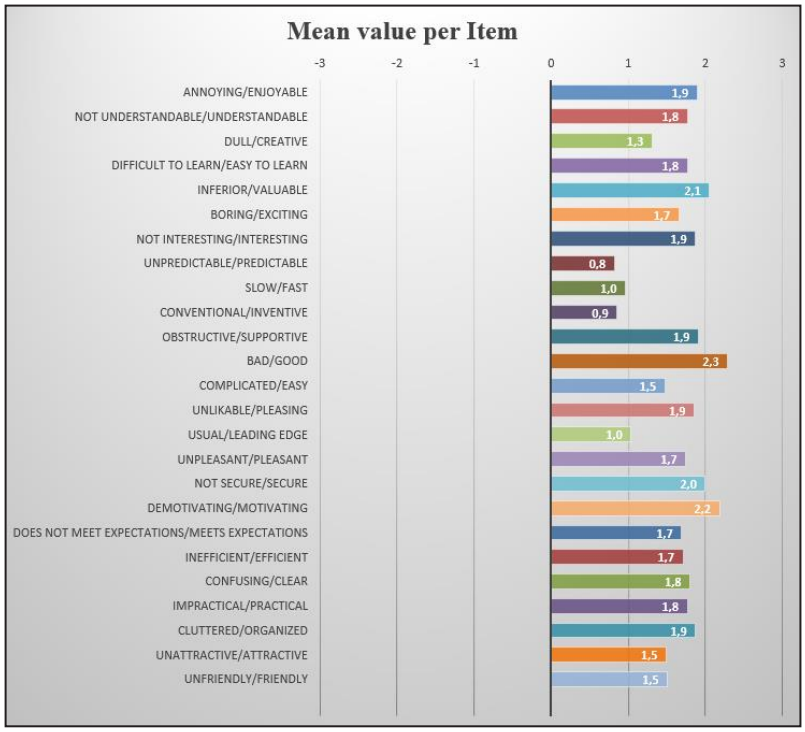

Figure 4. Bar chart of the mean score of each UEQ item

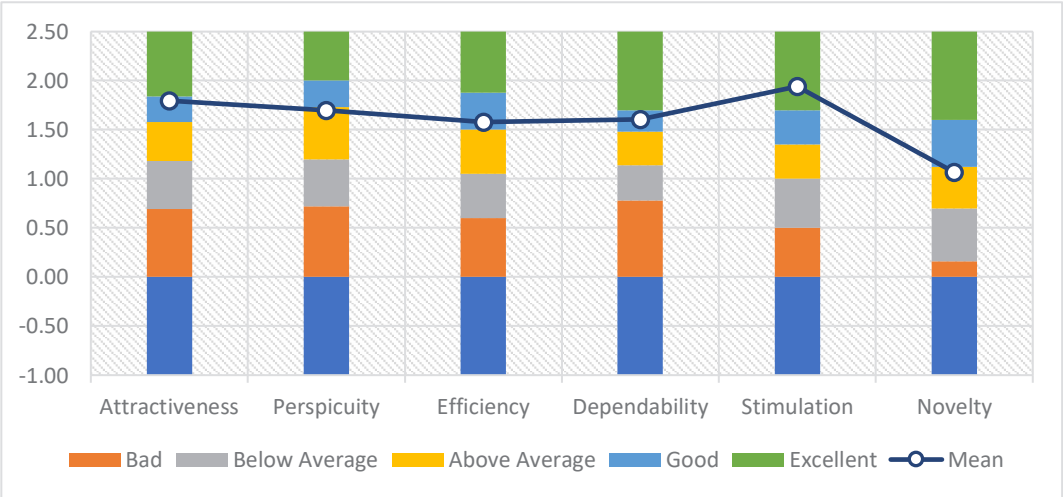

Figure 5. Bar chart of the mean score of each UEQ item

The benchmark compares average scores for each indicator with the UEQ score system in Table 4. Based on Figure 5 and Table 4, the UEQ analysis results indicate an excellent stimulation indicator. Furthermore, the attractiveness, efficiency, and reliability indicators are rated good, while the clarity and novelty indicators are above average.

Table 4. The UEQ mean score and value of the PyLo-AR app

UEQ Indicator	Mean Score	Value
Attractiveness	1,797	Good
Perspicuity	1,700	Above Average
Efficiency	1,577	Good
Dependability	1,605	Good
Stimulation	1,941	Excellent
Novelty	1,067	Above Average

2. Discussion

Based on the PyLo-AR application system, empirical usability testing was conducted with 55 students. The SUS measurement aims to quickly assess the usability of the PyLo-AR application from the student's perspective. The result of this testing yielded a score of 71, which falls into category B, indicating that the PyLo-AR application is acceptable or suitable for use in the learning process from the student's point of view (Pradini, Kriswibowo, & Ramdani, 2019).

The measurement of the user-friendly nature of the PyLo-AR application employed the User Experience Questionnaire (UEQ) instrument with the UEQ analysis technique (Schrepp et al., 2017) for a sample of 55 students. UEQ consists of 6 indicators to assess the user-friendly nature of a product. The UEQ indicators encompass Attractiveness, Clarity, Efficiency, Reliability, Stimulation, and Novelty. Based on the results of the UEQ testing, the PyLo-AR application is demonstrated to be user-friendly. This is evidenced in Table 4.2, which indicates that the stimulation indicator falls into the "excellent" category, signifying that the PyLo-AR application is highly engaging, exciting, and motivating for the students (Majgaard, Larsen, Lyk, & Morten, 2017). Meanwhile, for the attractiveness, efficiency, and reliability indicators, the PyLo-AR application falls into the "good" category, meaning it is seen as appealing, enjoyable, user-friendly, safe, and dependable in understanding the characteristics of each atomic model (Schrepp et al., 2017). The PyLo-AR application is also deemed innovative and creative in providing a new learning experience for the students (Tekedere & Göker, 2016). The PyLo-AR application falls into the "above average" category for clarity and novelty indicators. This suggests that the application is relatively simple, easy to understand, and straightforward to learn (Schrepp et al., 2017). Furthermore, the PyLo-AR application is sufficiently efficient, with an organized User Interface (UI) (Juniantari et al., 2021).

The measurement of the user-friendly nature of the PyLo-AR application using the UEQ instrument has been confirmed to be valid and reliable after it was identified that item 26 within the UEQ instrument was not valid due to the occurrence of the Spurious Overlap Effect during empirical testing. This effect involves an overestimation of the correlation involving item 26 of the UEQ instrument, which indicates that the correlation scores between items (3,26), (10,26), and (15,26) are not valid. This situation arose from the empirical pilot sample, which had previous experience with AR technology for gaming and extracurricular activities, as indicated by qualitative data from student personas who had experience using and creating an AR-based application. Consequently, item 26 of the novelty indicator in the UEQ instrument was biased compared to the other items within the novelty indicator (Hendryadi, 2021). Based on this issue, item 26 of the novelty indicator in the UEQ instrument was not used in the user-friendly testing process. The validity scores in the user-friendly testing for each indicator, after excluding item 26, can be observed in Table 5

Table 5. User-friendly validity testing

UEQ Indicator	correlation/ r_{count}	r_{table}	Value
Attractiveness	0,458	0,266 (N = 55 ; α = 5%)	Valid
Perspicuity	0,494		Valid
Efficiency	0,459		Valid
Dependability	0,371		Valid
Stimulation	0,546		Valid
Novelty	0,396		Valid

Based on the validity scores of each UEQ indicator, the reliability scores of the UEQ instrument for each indicator can be obtained and presented in Table 6.

Table 6. User-friendly reliability testing

UEQ Indicator	Cronbachs Alpha-Coefficient
Attractiveness	0,84
Perspicuity	0,80
Efficiency	0,77
Dependability	0,71
Stimulation	0,83
Novelty	0,85

With the validity and reliability testing of the UEQ instrument, after excluding item 26, the user-friendly nature of the PyLo-AR application can be generalized for the entire research population. It can be utilized in the learning process. This indicates that the application is suitable and effective for a broader context and can be confidently integrated into the learning process for all participants.

CONCLUSION

The PyLo-AR application possesses user-friendly features based on the results of the UEQ analysis. The UEQ results for the stimulus indicator are excellent, and the attractiveness, efficiency, and accuracy indicators are good. The clarity and novelty indicators are above average. Therefore, the PyLo-AR application meets the criteria for being easy to use and efficient.

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