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*Research Article*

# Technology acceptance of a wearable collaborative augmented reality system in learning chemistry among junior high school students

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Concepts related to molecular structure are often challenging for students to visualize and comprehend. Augmented reality has emerged as a promising solution to this problem, providing students with opportunities to manipulate and visualize chemical molecular structures to improve their understanding. Furthermore, collaborative learning environments have the potential to enhance student learning by fostering knowledge sharing and collaborative authoring. However, there is a dearth of research exploring students' acceptance of augmented reality in a collaborative learning context. Therefore, this study aims to investigate the technology acceptance of a wearable collaborative augmented reality system in chemistry education among junior high school students. Specifically, 124 students used *Microsoft® HoloLens 2* device to learn about chemical molecular structure. Data was collected using the Extended Technology Acceptance Questionnaire after participants used the system and analyzed using Partial Least Squares Structural Equation Modeling. The extended model takes knowledge sharing, collaborating learning, and collaborative authoring as exogenous variables with perceived ease of use and perceived usability and finally produces a structural model that leads to behavioral usage intentions. The hypotheses tested in this study were accepted as the relationships were significant. Knowledge sharing, collaborative learning, and collaborative authoring have a positive impact on perceived usefulness and perceived ease of use respectively; and perceived usefulness and perceived ease of use have significant effects on behavioral intention to use respectively. This study conclusively demonstrated the hypothesized relationships. Evidence from these results provides comprehensive insights that can help policymakers and educators better understand the factors influencing the adoption of wearable collaborative augmented reality.

Keywords: Augmented reality; Human-computer interaction; Technology acceptance model; Chemistry education; Junior high school; Collaborative learning

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## 1. Introduction

The visualization and comprehension of concepts related to molecular structure are often challenging for students (Aw et al., 2020; Fombona-Pascual et al., 2022). Recently, augmented reality [AR], an innovative technology for human-computer interaction, has emerged as a potential solution to this problem (Han & Sa, 2022; Iqbal & Sidhu, 2022). AR enables students to visualize

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and manipulate molecular structures (Mazzuco et al., 2022; Özçakır & Çakıroğlu, 2022), thereby facilitating their understanding of chemistry concepts (Fombona-Pascual et al., 2022; Mazzuco et al., 2022). Moreover, creating a collaborative learning environment may further enhance learning outcomes (Lin et al., 2022; Zhang et al., 2022), as students can collaborate to share knowledge (Eiris et al., 2022; Wei et al., 2022) and attempt collaborative authoring (Liaw et al., 2008).

Collaborative learning has many advantages, including improved problem-solving skills (Jovanović & Milosavljević, 2022), increased productivity (Zurba et al., 2022), enhanced learning efficiency (Liyanawatta et al., 2022), critical thinking (Okolie et al., 2022) and oral communication skills (Ko & Lim, 2022). Consequently, in recent years, education has shifted towards collaborative learning and the use of cutting-edge technology to facilitate collaborative teaching (Alam, 2022; Jyot et al., 2023). Numerous studies have investigated the effects of social media collaboration system on technology acceptance in extended models of collaborative learning and collaborative content authoring (Alenazy et al., 2019). As such, collaborative learning, collaborative authoring, and knowledge sharing behaviors have been recognized as important factors to consider in Technology Acceptance research (Al-Emran et al., 2020; Alenazy et al., 2019; Liaw et al., 2008).

Despite the promising theoretical research on the impact of collaborative learning, collaborative authoring, and knowledge sharing on technology acceptance, there has been no specific study examining the technology acceptance of wearable collaborative augmented reality [WcAR] systems in junior high school chemistry education (Mazzuco et al., 2022). Among numerous technology acceptance models, the Technology Acceptance Model (TAM) remains the most used approach for exploring AR users' acceptance (Jang et al., 2021; Oyman et al., 2022). TAM is highly influential and versatile, enabling a better understanding of the impact of exogenous variables on technology acceptance (Haugstvedt & Krogstie, 2012; He et al., 2023; Ibili et al., 2019; Jang et al., 2021; Lin & Chen, 2017; Oyman et al., 2022). Determinants of perceived usefulness and perceived ease of use have been studied in the context of some technologies, it is still necessary to investigate the determinants of perceived usefulness and perceived ease of use in the context of new technologies. However, there is a lack of research on the factors that influence the perceived usefulness and ease of use of collaborative learning with augmented reality technology (Mazzuco et al., 2022). The lack of research on wearable collaborative augmented reality learning tools is even more apparent, as this is a new research field (Feng et al., 2023). Due to the existing research gap, it is currently unknown how junior high school students perceive this technology.

Moreover, there is limited research on the implementation of wearable collaborative augmented reality technology in chemistry classroom instruction (Pathania et al., 2023). Furthermore, an integrated theoretical model that combines the TAM model with constructs such as knowledge sharing (Alenazy et al., 2019), collaborative learning (Liaw et al., 2008), collaborative authoring (Liaw et al., 2008), and behavioral intention to use (Davis, 1989) has not yet been developed and assessed within the realm of WcAR. Therefore, it is essential to provide a detailed explanation within the TAM framework of how WcAR technology is applied in middle school chemistry education.

Therefore, Hence, the theoretical foundation of this study is built upon the TAM proposed by Davis (1989), which has been expanded to include six structures: perceived ease of use (Davis, 1989) and perceived usefulness (Davis, 1989), knowledge sharing (Alenazy et al., 2019), collaborative learning (Liaw et al., 2008), collaborative authoring (Liaw et al., 2008), and behavioral intention to use (Davis, 1989). In this model, knowledge sharing, collaborative learning, and collaborative authoring are considered external factors influencing perceived usefulness and perceived ease of use, while the latter two mediate the relationship between external factors and usage behavior intentions.

Therefore, the primary objective of this study is to investigate how the integration of learners' knowledge sharing, collaborative authoring, and collaborative learning structures can be incorporated into the TAM model when utilizing the WcAR system in chemistry education.

Additionally, the study aims to explore the potential application of WcAR in future junior high chemistry education.

## 2. Research Model and Hypotheses

### 2.1. Technology Acceptance Model [TAM]

Davis (1989) developed the TAM to explain technology acceptance that is general and capable of describing user behaviors across technologies. The TAM consists of two exogenous constructs: perceived usefulness and perceived ease of use. Perceived usefulness is defined as " a person feels that adopting a certain system will be easy (Davis, 1989)," while perceived ease of use is defined as "a person's sense that utilizing a certain system is useful (Davis, 1989)." Studies have shown that both perceived ease of use and perceived usefulness have a positive influence on software usage intentions (Alenazy et al., 2019; Cabero-Almenara & Perez, 2018). Therefore, this study proposed two hypotheses:

H1: Perceived usefulness has a significant impact on learners' behavior intention to use the WcAR system.

H2: Perceived ease of use has a significant impact on learners' behavior intention to use the WcAR system.

TAM has been extended to include different techniques (Alenazy et al., 2019), different backgrounds (Alenazy et al., 2019; Cabero-Almenara & Perez, 2018) and different users (Fussell & Truong, 2022; Han & Sa, 2022; Lu et al., 2023). Some studies have also extended the TAM to include external latent variables to examine user acceptance of technology use (Fussell & Truong, 2022; Natasia et al., 2022). However, a meta-analysis conducted by Avcı and Gulbahar (2013) found that the system itself had the most significant influence on users, and this external variable has been the most successful addition to the TAM (Avcı & Gulbahar, 2013; Davis, 1989).

### 2.2. The Extended model

#### *2.2.1. Knowledge sharing*

Knowledge sharing refers to disseminating various resources among individuals participating in a particular activity (Alenazy et al., 2019). Previous research suggests that there is a positive correlation between knowledge sharing and the perceived usefulness and ease of use of specific technologies (Al-Emran et al., 2020; Alenazy et al., 2019). Furthermore, studies have indicated that knowledge sharing is a significant predictor of users' behavioral intentions to use technologies (Alenazy et al., 2019). Thus, the following hypotheses were put forward:

H3: Knowledge sharing has a significant impact on perceived usefulness of the WcAR system.

H4: Knowledge sharing has a significant impact on perceived ease of use of the WcAR system.

#### *2.2.2. Collaborative learning*

Collaborative learning occurs when students collaborate and share their knowledge and abilities to achieve specified learning objectives (Liaw et al., 2008). The degree to which collaborative learning systems are utilized for collaborative learning impacts students' perceived ease of use and perceived usefulness of the system (Khan et al., 2021). In the context of WcAR system-assisted chemistry teaching, when utilized effectively, collaborative learning can enhance the learning process by facilitating communication and interaction (Huang et al., 2010; Huang et al., 2016). Additionally, collaborative learning increases engagement in the learning process and exposes students to learning media (Liaw et al., 2008). Thus, the researchers proposed the following hypothesis:

H5: Collaborative Learning has a significant impact on perceived usefulness of the WcAR system.

H6: Collaborative Learning has a significant impact on perceived ease of use of the WcAR system.

*2.2.3. Collaborative authoring*

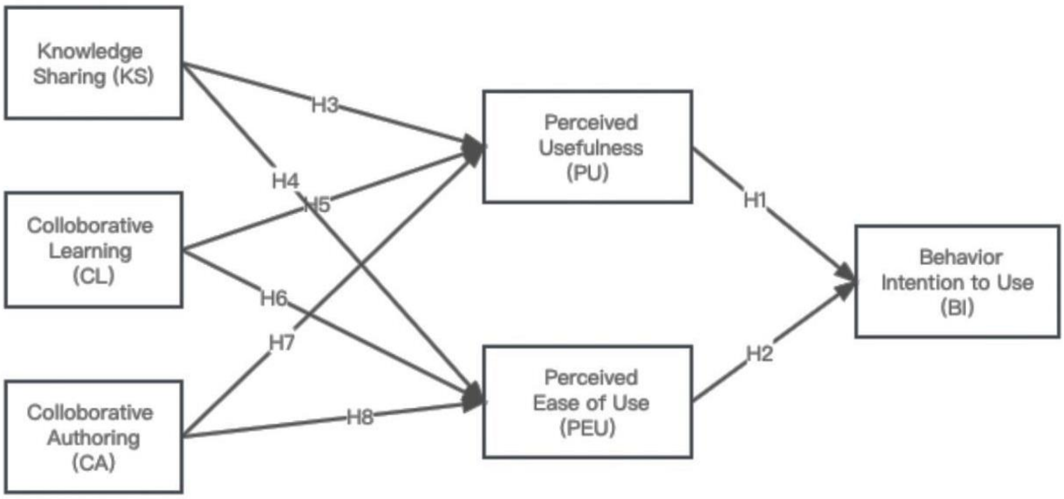
Collaborative authoring primarily enhances collaborative learning by allowing for the reuse of existing learning materials and collaborative learning functions to achieve specific learning objectives (Liaw et al., 2008). In the WcAR system, the collaborative authoring environment has been transformed from a face-to-face real-world setting to a face-to-face virtual world. Collaborative authoring has been introduced as a new method to assist learning with the help of technology, mainly improving the reusability of the fusion of technology and knowledge output (Khan et al., 2021). Previous research has shown that collaborative authoring is useful for educational purposes with technological support (Ramirez & Monterola, 2022). In addition, WcAR system can facilitate interaction and collaboration among students, encouraging them to become active learners. Therefore, using WcAR system in education can enhance student engagement and social interaction. By adding collaborative authoring in technology-assisted teaching, students often gain different knowledge and skills (Ramirez & Monterola, 2022), which may increase the practicality and ease of use of the WcAR system. Based on the above discussion, the following hypothesis is proposed:

H7: Collaborative authoring has a significant impact on perceived usefulness of the WcAR system.

H8: Collaborative authoring has a significant impact on perceived ease of use of the WcAR system.

The overall theoretical model diagram and assumptions are shown in Figure 1.

Figure 1
*The theoretical model*




## 3. Method

### 3.1. Research Method and Sample

This study employed a quantitative research approach guided by the post-positivist paradigm, utilizing a single-group posttest experimental design for experimentation. This study was conducted in a junior high school in mainland China. Three classes from grade 6 were selected and a total of 124 students agreed to participate in the investigation. Table 1 presents the demographics of the participants. All participants received permission from their parents or guardians to participate in the research and completed the informed consent form. Participants remained anonymous throughout the study.

Table 1
*Demographics*

| *Variable* | *Frequency* | *Percentage (%)* |
|---|---|---|
| Gender | | |
| Male | 63 | 50.80 |
| Female | 61 | 49.20 |
| Age | | |
| 11 | 15 | 12.09 |
| 12 | 79 | 63.70 |
| 13 | 30 | 24.21 |
| Student use experience with AR | | |
| Often use | 0 | 0 |
| Sometimes use | 0 | 0 |
| Rarely use | 2 | 1.61 |
| Never use | 122 | 98.39 |
| I don't know | 0 | 0 |

### 3.2. Instrument

In this study, a questionnaire was developed to assess the technology acceptance of the chemical WcAR system. The questionnaire was based on the measurement dimensions of previously published studies (Al-Emran et al., 2020; Alenazy et al., 2019; Liaw et al., 2008), and was adjusted slightly to fit the research content of this study. The questionnaire included 15 items of three structures of knowledge sharing, collaborating learning, and collaborative authoring, and 15 items of TAM structure. Therefore, the questionnaire had a total of 30 items. The original version of the questionnaire was subjected to content validation (Al-Emran & Teo, 2020; Alenazy et al., 2019; Liaw et al., 2008) to ensure its reliability and validity.

The final version of this questionnaire was translated into Mandarin and used a 7-point Likert scale, with six reverse questions included to increase the reliability and validity of the questionnaire (Natasia et al., 2022).

### 3.3. AR Learning Environment

The researchers developed WcAR for learning chemistry system independently. The system is operated using *Microsoft® HoloLens 2* AR glasses and can be operated using only gestures, without the need for additional equipment assistance. This system encompasses the first 20 elements of the periodic table, offering an interactive platform where users can access corresponding atoms upon interacting with the elements. Moreover, it allows users to construct relevant molecules using the provided atoms. The educational content of the system strictly adheres to the Chinese compulsory education junior high school chemistry curriculum textbooks (2022 edition), encompassing the pertinent contents of elements, atoms, and molecules. Two participants engage with the system via separate *Microsoft® HoloLens 2* devices, both of which are linked to a central server. This linkage ensures that both students can collectively view the periodic table through their *Microsoft® HoloLens 2* devices.

As depicted in Figure 2, two students interact with the system using gesture recognition in *Microsoft® HoloLens 2*. They each retrieve a hydrogen [H] atom and bring them into proximity, consequently forming a hydrogen molecule. In instances where the combination is accurate, an auditory prompt signals the correctness of their arrangement. Importantly, the augmented reality environment presented to the students encompasses not only the periodic table, atoms, and molecules but also extends to the physical walls of the classroom. So, participants can simultaneously see the virtual and natural worlds, which helps prevent issues such as balance problems, dizziness, loss of color vision, nausea, and vomiting that may occur when interacting with virtual environments that lack depth perception.

Figure 2
*Microsoft® HoloLens 2 AR glasses*

### 3.4. Research Design and Experimental Procedure

The present study employed a single-group experimental post-test quantitative research design. The research was conducted in three phases. First, the researchers introduced the *Microsoft® HoloLens 2* AR glasses to the students and provided training on how to wear and operate them in the initial class, as detailed in Table 2. Secondly, in the subsequent class, students were randomly paired and collaborated in using the periodic table of elements to create various molecules while exploring the relationship between molecules and atoms, as outlined in Table 3. Throughout this task, students were encouraged to share knowledge through language, gestures, and other behaviors. Finally, upon completing the experimental task, researchers distributed questionnaires to the students, collected the datas and concluded the research experiment.

Table 2
Description of Unit 1 Contents

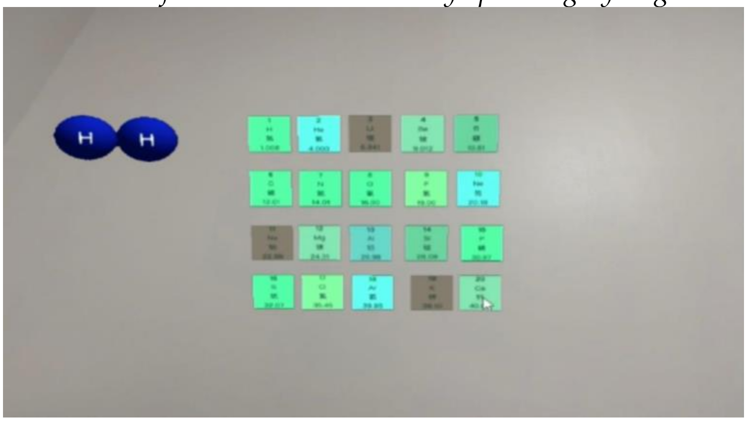
| *Stage* | *Activity* |
|---|---|
| Before the course starts | Send informed consent forms to students' parents before the course starts and collect research informed consent forms after the course begins. |
| Part 1: Introduction to Hololens 2 and its basic usage methods | The teacher can demonstrate how to wear and adjust the Hololens 2 device and demonstrate basic operations by showcasing the actual Hololens 2 device. |
| Part 2: Familiarization with the user interface and interaction methods of Hololens 2 | The teacher can use the projection function of Hololens 2 to share the device screen on a large screen and demonstrate the use of different gestures and voice commands. |
| Part 3: Introduction to chemistry learning applications and hands-on practice | The teacher can project the screen or use a computer screen to show students the interface and functions of the chemistry learning application. The teacher demonstrates how to select and manipulate molecular models, simulate chemical reactions, etc. |
| Part 4: Utilizing collaboration and sharing features | The teacher created a collaborative scene (Synthesize carbon dioxide molecules) and invite students to join through Hololens 2. Students can share their operations and views in real time within the same scene for collaborative learning. |

Table 3
*Description of Unit 2 Contents*

| *Stage* | *Activity* |
|---|---|
| Part 1 | "Students are required to use Hololens 2 devices in class to view videos elucidating the atomic composition leading to the formation of molecules (see Figure 3). Additionally, the instructor will provide supplementary explanations on the formation processes of water molecules, oxygen molecules, and hydrogen molecules. Students will then collaborate to discuss and simulate an analysis of a molecule of their choice, exploring its practical applications in everyday life." |
| Part 3 | Students are instructed to collaborate in pairs using Hololens 2 devices to observe and manipulate the formation of hydrogen molecules, water molecules, or oxygen molecules (see Figure 4). |
| Part 4 | Encourage students to collaboratively discuss the relationship between atoms and molecules while working together to operate Hololens 2 devices. |

Figure 3
*Video of water molecules (source material from Youku)*


Figure 4
*Screenshots of students collaboratively operating hydrogen molecules*




### 3.5. The Validity and Reliability of the Study

Throughout the experimental process, two technical personnel ensured the stability of the technology by conducting pre-experimental device testing, troubleshooting, and providing technical support. To ensure the effectiveness and reliability of the study, the same instructor conducted the experiment, minimizing the potential influence of individual teaching styles on the experimental process. Furthermore, the overall teaching approach of the instructor remained consistent with previous teaching instances, mitigating the impact of teaching methods on the experimental procedures.

### 3.6. Demonstration Evaluation

In this study, confirmatory tests were performed on an adapted and extended version of the TAM (Davis, 1989), which was derived from previous theoretical derivations (Al-Emran et al., 2020) and empirical evidence conceptualization (Davis, 1989; Liaw et al., 2008). The PLS-SEM analysis was conducted using SmartPLS in this study.

## 4. Result

### 4.1. Measurement Model Assessment

Confirmatory factor analysis [CFA] investigated a total of 124 questionnaires. Table 2 shows the analysis of the questionnaire's internal consistency, reliability, and convergent validity. According to Table 4, that all α values and CR are significant with values greater than 0.7, indicating the items of the questionnaire have good internal consistency reliability. An analysis was then performed on the average variance extracted [AVE] values of the constructs to assess the effectiveness of the convergence. Both left, and correct values of AVE exceed the minimum threshold of 0.5, suggesting that these structures explain more than half of the variance in their metrics. Table 5 reveals that all Pearson correlation coefficients are less than the square root of the convergent validity (Bold numbers in the table show the square root value of AVE and the value in the lower triangle is the Pearson correlation coefficient.) and as shown in Table 6, all values are less than .85. Therefore, the structural model in this study exhibits discriminant validity.

Table 4
*Cronbach's a (a), composite reliability (CR) and average variance extracted (AVE)*

| | *CL* | *CA* | *KS* | *PEU* | *PU* | *BI* |
|---|---|---|---|---|---|---|
| α | .882 | .861 | .879 | .889 | .893 | .860 |
| CR | .914 | .900 | .912 | .919 | .921 | .899 |
| AVE | .680 | .644 | .674 | .693 | .701 | .642 |

*Note.* BI: behavior intention to use; CL: collaborative learning; CA: collaborative authoring; KS: knowledge sharing; PEU: perceived ease of use; PU: perceived usefulness.

Table 5
*Discriminant validity*

| | *Convergent validity* | *Discriminant validity* | | | | | |
|---|---|---|---|---|---|---|---|
| | AVE | BI | CL | CA | KS | PEU | PU |
| BI | 0.64 | **0.80** | | | | | |
| CL | 0.68 | 0.54 | **0.82** | | | | |
| CA | 0.64 | 0.52 | 0.60 | **0.80** | | | |
| KS | 0.67 | 0.41 | 0.49 | 0.57 | **0.82** | | |
| PEU | 0.69 | 0.59 | 0.57 | 0.58 | 0.56 | **0.83** | |
| PU | 0.70 | 0.55 | 0.61 | 0.66 | 0.63 | 0.64 | **0.84** |

*Note.* BI: behavior intention to use; CL: collaborative learning; CA: collaborative authoring; KS: knowledge sharing; PEU: perceived ease of use; PU: perceived usefulness.

Table 6
*Heterotrait-monotrait ratio (HTMT)*

| | *BI* | *CL* | *CA* | *KS* | *PEU* |
|---|---|---|---|---|---|
| CL | 0.619 | | | | |
| CA | 0.589 | 0.69 | | | |
| KS | 0.468 | 0.548 | 0.649 | | |
| PEU | 0.667 | 0.642 | 0.658 | 0.627 | |
| PU | 0.619 | 0.687 | 0.744 | 0.701 | 0.714 |

*Note.* BI: behavior intention to use; CL: collaborative learning; CA: collaborative authoring; KS: knowledge sharing; PEU: perceived ease of use; PU: perceived usefulness.

### 4.2. Structural Model Assessment

This study analyzed the direct path coefficients of structural models, representing the relationship between structures (see Table 7). Analysis of the coefficient relationship in the original TAM variable showed support for H1, as the PU- BI pathway had a positive effect (β = 0.281, $p < .01$), but the effect was low. Furthermore, the PEU- BI (β = 0.412, $p < .001$) path coefficient showed a significantly positive effect; thus, H2 was confirmed. The coefficient for the KS-PU path was high (β = 0.314, $p < .001$), thus hypothesis H3 holds. H4 was also accepted because of the minor significant effect in the KS-PEU pathway (β = 0.283, $p < .001$). The CL-PU (β = 0.271, $p < .001$) relationship was large and significant, and the CL-PEU (β = 0.284, $p < .001$) relationship remained significant, supporting H5 and H6, respectively. Finally, the CA-PU (β = 0.315, $p < .01$) pathway exhibited an effect significant at the $p < .01$ level, while the CA-PEU (β = 0.247, $p < .001$) also demonstrated significance. These results support H7 and H8. See Figure 5 for a complete representation of the loading.

Table 7
*Descriptive Analysis and Path Coefficients*

| | *Original sample (O)* | *Mean* | *SD* | *T statistics (\|O/STDEV\|)* | *p-values* |
|---|---|---|---|---|---|
| CL→PEOU | 0.28 | 0.29 | 0.09 | 3.32 | 0.00 |
| CL→PU | 0.27 | 0.27 | 0.08 | 3.52 | 0.00 |
| CA→PEOU | 0.25 | 0.25 | 0.10 | 2.60 | 0.01 |
| CA→PU | 0.32 | 0.32 | 0.10 | 3.19 | 0.00 |
| KS→PEOU | 0.28 | 0.28 | 0.08 | 3.60 | 0.00 |
| KS→PU | 0.31 | 0.31 | 0.07 | 4.33 | 0.00 |
| PEOU→BI | 0.41 | 0.42 | 0.11 | 3.92 | 0.00 |
| PU→BI | 0.281 | 0.28 | 0.103 | 2.725 | 0.006 |

*Note.* BI: behavior intention to use; CL: collaborative learning; CA: collaborative authoring; KS: knowledge sharing; PEU: perceived ease of use; PU: perceived usefulness.

Figure 5
*Confirmation model results*

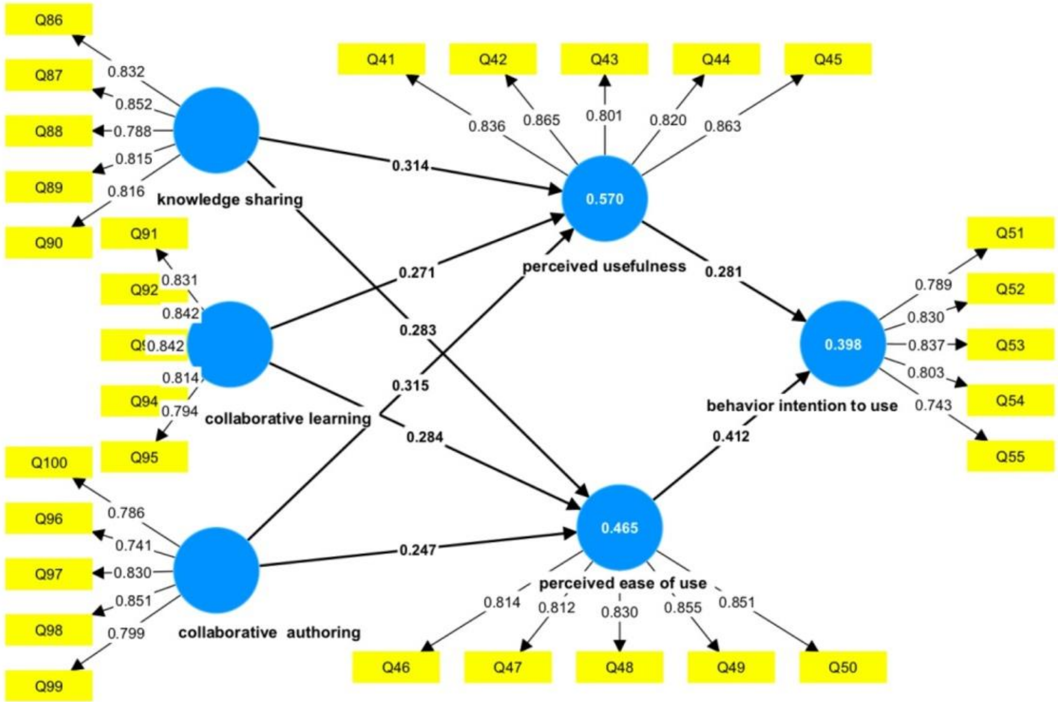


Table 8
*Effect size ($f^2$)*

| | *BI* | *PEU* | *PU* |
|---|---|---|---|
| CL | | 0.091 | 0.103 |
| CA | | 0.061 | 0.124 |
| KS | | 0.096 | 0.148 |
| PEU | 0.167 | | |
| PU | 0.078 | | |

*Note.* BI: behavior intention to use; CL: collaborative learning; CA: collaborative authoring; KS: knowledge sharing; PEU: perceived ease of use; PU: perceived usefulness.

## 5. Discussion

As shown in Table 8, the TAM structure of Davis' (1989) perceived ease of use was found to have a greater impact on learners' behavior intention to use compared to perceived usefulness. This result is inconsistent with the findings of Barrett et al. (2020) and Sagnier et al. (2020). This may be attributed to the fact that learners place more emphasis on the ease of use of the technology rather than its usefulness when using knowledge intensive WcAR system. In this study, the WcAR system is designed for educational purposes, allowing junior high school students to navigate virtual space interfaces through gesture recognition, grab virtual objects, and build through collaborative learning. Therefore, when designing a WcAR system for chemical knowledge, more attention should be paid to the ease of use of the new system integrated with new technologies in educational applications. Besides, when designing collaborative learning activities, students' perceptual and psychological processes should be taken into consideration, as these processes increase the ease of use of new technologies and devices.

Compared to collaborative learning and collaborative authoring provided by the device, knowledge sharing has the most significant impact on perceived usefulness and perceived ease of use (See table 6). The results of this study are consistent with previous literature that found a positive correlation between knowledge sharing and perceived usefulness and ease of use (Al-Emran et al., 2020; Cheung & Vogel, 2013). Al-Emran and Teo (2020) found that the content of systematic knowledge sharing affects the effectiveness of knowledge sharing. In this study, the *Microsoft® HoloLens 2* device requires only gesture-based interactions for the utilization of the WcAR system, thereby fostering collaborative student engagement with learning content related to chemical molecules and atoms. Consequently, this facilitates knowledge sharing and communication among students while significantly bolstering participants' perceived usefulness of the system. In the WcAR system, knowledge sharing occurs through face-to-face communication and collaborative building of chemical molecules, which can provide students with a sense of sustained participation. This collaborative learning approach, which does not change students' language communication habits, adds the influence of perceived ease of use on intention to use in this study. Students can better understand the chemical knowledge learned through knowledge sharing and view the experience as a new and exciting learning method. The implication of this result is that WcAR can effectively improve students' participation, enrich chemistry learning activities through knowledge sharing, and more easily influence the cognitive processes of students who are easily distracted or less affected by real-life learning environments.

Similarly, the impact of collaborative learning on perceived usefulness and perceived ease of use is not surprising, as learners' collaborative operations in devices will improve learners' acceptance of new technology. When learners encounter unfamiliar operations, they can solve operation problems through peer collaboration, thereby completing tasks. Alenazy et al. (2019) found that students have a strong tendency when they used new technology integrating collaborative learning, and their willingness to use it is very strong. These results suggest that learners are likely to perceive collaborative learning strategies within the WcAR system as both effortless and advantageous. Consequently, their inclination to employ these strategies becomes substantial. By jointly addressing complexities and learning from one another, learners find collaborative learning to be an effective method for mastering the technology (Khan et al., 2021). This positive experience can result in perceived ease of use and usefulness for the WcAR system.

Collaborative authoring has an impact on perceived usefulness and perceived ease of use. Through collaborative authoring, students might realize that constructing chemical molecules using the WcAR system is, in fact, a relatively straightforward task. This understanding arises from their collaborative problem-solving endeavors and the shared exchange of experiences concerning system operation and chemical concepts. Such collaborative authoring could alleviate students' apprehensions about technical operations (Al-Emran & Teo, 2020), consequently heightening their perception of system ease of use. Through collaborative authoring with peers, students garner greater satisfaction and a sense of accomplishment during problem-solving and creative processes (Alenazy et al., 2019; Liaw et al., 2008). This affirmative engagement could foster a perception of usefulness in students regarding the utilization of the WcAR system.

One limitation of this study is that all participants were from a single school in China, which may impact the generalizability of the research findings. Therefore, future research should aim to include participants from diverse cultural backgrounds and educational institutions to enhance the external validity of the study, and qualitative methods also should be used because qualitative data can provide perceptions into the specific reasons for the structure of the relationship. For example, the reasons for the impact of collaborative authoring on the perceived ease of use of the device. Subsequent studies can also explore its impact on students with different learning styles, different learning experiences, and so on, to further explore the essential impact of integrating collaborative technology into AR on chemistry education.

## 6. Conclusion

This study explored junior high school students' acceptance of a WcAR for learning chemistry system. The results show that collaborative learning, knowledge sharing, and collaborative authoring using WcAR are associated with different degrees of the structure of technology acceptance. Junior high school students are highly likely to adopt WcAR for chemistry learning. Knowledge sharing has the greatest impact on the perceived ease of use and perceived usefulness of WcAR. Therefore, the design of the WcAR environment can provide a more open knowledge exploration and sharing environment to increase the frequency of students' knowledge exchange, which may increase students' perception of the usefulness of the WcAR. In addition, collaborative learning and collaborative authoring also have an impact on perceived ease of use and perceived usefulness. This study can provide researchers with practical and theoretical basis for the use of WcAR in chemistry education and encourage students and researchers to use WcAR to improve teaching effects through collaborative learning strategies.

**Author contributions:** All the authors contributed significantly to the conceptualization, analysis, and writing of this paper.

**Data availability:** The datasets generated during and/or analysed during the current study are not publicly available due ethical restrictions to protect the privacy of the participants. However, they are available from the corresponding author on reasonable request.

**Declaration of interest:** No conflict of interest is declared by authors.

**Ethics declaration:** This study has been approved by the University of Malaya Research Ethics Committee (UMREC). The research ethics approval number for this study is UM.TNC2/UMREC_2547.

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## References

Al-Emran, M., Mezhuyev, V., & Kamaludin, A. (2020). Towards a conceptual model for examining the impact of knowledge management factors on mobile learning acceptance. *Technology in Society, 61,* 101247. https://doi.org/10.1016/j.techsoc.2020.101247

Alam, A. (2022). Employing adaptive learning and intelligent tutoring robots for virtual classrooms and smart campuses: reforming education in the age of artificial intelligence. In R. N. Shaw, S. Das, V. Piuri, & M. Bianchini (Eds.), *Advanced computing and intelligent technologies* (pp. 395-406). Springer.

Alenazy, W. M., Mugahed, A.-R. W., & Khan, M. S. (2019). Validation of TAM model on social media use for collaborative learning to enhance collaborative authoring. *IEEE Access, 7,* 71550-71562. https://doi.org/10.1109/ACCESS.2019.2920242

Avcı, Y. U., & Gulbahar, Y. (2013). Technology acceptance model: A review of the prior predictors. *Ankara University Journal of Faculty of Educational Sciences, 46*(1), 89-109. https://doi.org/10.1501/Egifak_0000001275

Aw, J. K., Boellaard, K. C., Tan, T. K., Yap, J., Loh, Y. P., Colasson, B., Blanc, É., Lam, Y., & Fung, F. M. (2020). Interacting with three-dimensional molecular structures using an augmented reality mobile app. *Journal of Chemical Education, 97*(10), 3877-3881. https://doi.org/10.1021/acs.jchemed.0c00387

Barrett, A., Pack, A., Guo, Y., & Wang, N. (2020). Technology acceptance model and multi-user virtual reality learning environments for Chinese language education. *Interactive Learning Environments, 31*(3), 1665-1682. https://doi.org/10.1080/10494820.2020.1855209

Cabero-Almenara, J., & Perez. (2018). TAM model validation adoption of augmented reality through structural equations. *Estudios sobre Educación, 34,* 129-153. https://core.ac.uk/reader/157758588

Cheung, R., & Vogel, D. (2013). Predicting user acceptance of collaborative technologies: An extension of the technology acceptance model for e-learning. *Computers & Education, 63,* 160-175. https://doi.org/10.1016/j.compedu.2012.12.003

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319-340. https://doi.org/10.2307/249008

Eiris, R., Wen, J., & Gheisari, M. (2022). iVisit-Collaborate: Collaborative problem-solving in multiuser 360-degree panoramic site visits. *Computers & Education, 177,* 104365. https://doi.org/10.1016/j.compedu.2021.104365

Feng, S., Liu, Y., Zhang, Q., He, W., Zhang, X., Wang, S., & Billinghurst, M. (2023). Parallel or cross? Effects of two collaborative modes on augmented reality co-located operations. *International Journal of Human–Computer Interaction.* Advance Online Publication. https://doi.org/10.1080/10447318.2023.2202574

Fombona-Pascual, A., Fombona, J., & Vicente, R. (2022). Augmented Reality, a Review of a Way to Represent and Manipulate 3D Chemical Structures. *Journal of Chemical Information and Modeling, 62*(8), 1863-1872. https://doi.org/10.1021/acs.jcim.1c01255

Fussell, S. G., & Truong, D. (2022). Using virtual reality for dynamic learning: an extended technology acceptance model. *Virtual Reality, 26*(1), 249-267. https://doi.org/10.1007/s10055-021-00554-x

Han, J.-H., & Sa, H. J. (2022). Acceptance of and satisfaction with online educational classes through the technology acceptance model (TAM): the COVID-19 situation in Korea. *Asia Pacific Education Review, 23*(3), 403-415. https://doi.org/10.1007/s12564-021-09716-7

Haugstvedt, A. C., & Krogstie, J. (2012). *Mobile augmented reality for cultural heritage: A technology acceptance study* [Paper presentation]. IEEE International Symposium on Mixed and Augmented Reality (ISMAR), Atlanta, GA, USA.

He, S., Jiang, S., Zhu, R., & Hu, X. (2023). The influence of educational and emotional support on e-learning acceptance: An integration of social support theory and TAM. *Education and Information Technologies, 28,* 11145–11165. https://doi.org/10.1007/s10639-023-11648-1

Huang, H.-M., Rauch, U., & Liaw, S.-S. (2010). Investigating learners' attitudes toward virtual reality learning environments: Based on a constructivist approach. *Computers & Education, 55*(3), 1171-1182. https://doi.org/10.1016/j.compedu.2010.05.014

Huang, T.-C., Shu, Y., Yeh, T.-C., & Zeng, P.-Y. (2016). Get lost in the library?An innovative application of augmented reality and indoor positioning technologies. *The Electronic Library, 34*(1), 99-115. https://doi.org/10.1108/EL-08-2014-0148

Ibili, E., Resnyansky, D., & Billinghurst, M. (2019). Applying the technology acceptance model to understand maths teachers' perceptions towards an augmented reality tutoring system. *Education and Information Technologies, 24*(5), 2653-2675. https://doi.org/10.1007/s10639-019-09925-z

Iqbal, J., & Sidhu, M. S. (2022). Acceptance of dance training system based on augmented reality and technology acceptance model (TAM). *Virtual Reality, 26*(1), 33-54. https://doi.org/10.1007/s10055-021-00529-y

Jang, J., Ko, Y., Shin, W. S., & Han, I. (2021). Augmented reality and virtual reality for learning: an examination using an extended technology acceptance model. *IEEE Access, 9,* 6798-6809. https://doi.org/10.1109/ACCESS.2020.3048708

Jovanović, A., & Milosavljević, A. (2022). VoRtex metaverse platform for gamified collaborative learning. *Electronics, 11*(3), 317. https://doi.org/10.3390/electronics11030317

Jyot, K. D., Niraja, S., & Irum, A. (2023). Technology-enabled language leaning: mediating role of collaborative learning. *Journal of Language and Education, 9*(1), 89-101. https://doi.org/10.17323/jle.2023.12359

Khan, M. N., Ashraf, M. A., Seinen, D., Khan, K. U., & Laar, R. A. (2021). Social media for knowledge acquisition and dissemination: The impact of the COVID-19 pandemic on collaborative learning driven social media adoption [Original Research]. *Frontiers in Psychology, 12,* 648253. https://doi.org/10.3389/fpsyg.2021.648253

Ko, E. G., & Lim, K. Y. (2022). Promoting english learning in secondary schools: design-based research to develop a mobile application for collaborative learning. *The Asia-Pacific Education Researcher, 31*(3), 307-319. https://doi.org/10.1007/s40299-021-00562-0

Liaw, S.-S., Chen, G.-D., & Huang, H.-M. (2008). Users' attitudes toward Web-based collaborative learning systems for knowledge management. *Computers & Education, 50*(3), 950-961. https://doi.org/10.1016/j.compedu.2006.09.007

Lin, C.-P., Yang, S.-J., Lin, K.-Y., Looi, C.-K., & Chen, Y.-H. (2022). Explorations of two approaches to learning CT in a game environment for elementary school students. *Journal of Computers in Education, 9*(2), 261-290. https://doi.org/10.1007/s40692-021-00203-x

Lin, H.-F., & Chen, C.-H. (2017). Combining the technology acceptance model and uses and gratifications theory to examine the usage behavior of an augmented reality tour-sharing application. *Symmetry, 9*(7), 9070113. https://doi.org/10.3390/sym9070113

Liyanawatta, M., Yang, S.-H., Liu, Y.-T., Zhuang, Y., & Chen, G.-d. (2022). Audience participation digital drama-based learning activities for situational learning in the classroom. *British Journal of Educational Technology, 53*(1), 189-206. https://doi.org/10.1111/bjet.13160

Lu, J., Rong, D., Lev, B., Liang, M., Zhang, C., & Gao, Y. (2023). Constraints affecting the promotion of waste incineration power generation project in China: A perspective of improved technology acceptance model. *Technological Forecasting and Social Change, 186*, 122165. https://doi.org/10.1016/j.techfore.2022.122165

Mazzuco, A., Krassmann, A. L., Reategui, E., & Gomes, R. S. (2022). A systematic review of augmented reality in chemistry education. *Review of Education, 10*(1), e3325. https://doi.org/10.1002/rev3.3325

Natasia, S. R., Wiranti, Y. T., & Parastika, A. (2022). Acceptance analysis of NUADU as e-learning platform using the Technology Acceptance Model (TAM) approach. *Procedia Computer Science, 197,* 512-520. https://doi.org/10.1016/j.procs.2021.12.168

Okolie, U. C., Igwe, P. A., Mong, I. K., Nwosu, H. E., Kanu, C., & Ojemuyide, C. C. (2022). Enhancing students' critical thinking skills through engagement with innovative pedagogical practices in Global South. *Higher Education Research & Development, 41*(4), 1184-1198. https://doi.org/10.1080/07294360.2021.1896482

Oyman, M., Bal, D., & Ozer, S. (2022). Extending the technology acceptance model to explain how perceived augmented reality affects consumers' perceptions. *Computers in Human Behavior, 128*, 107127. https://doi.org/10.1016/j.chb.2021.107127

Özçakır, B., & Çakıroğlu, E. (2022). Fostering spatial abilities of middle school students through augmented reality: Spatial strategies. *Education and Information Technologies, 27*(3), 2977-3010. https://doi.org/10.1007/s10639-021-10729-3

Pathania, M., Mantri, A., Kaur, D. P., Singh, C. P., & Sharma, B. (2023). A Chronological Literature Review of Different Augmented Reality Approaches in Education. *Technology, Knowledge and Learning, 28*(1), 329-346. https://doi.org/10.1007/s10758-021-09558-7

Ramirez, H. J. M., & Monterola, S. L. C. (2022). Co-creating scripts in computer-supported collaborative learning and its effects on students' logical thinking in earth science. *Interactive Learning Environments, 30*(5), 908-921. https://doi.org/10.1080/10494820.2019.1702063

Sagnier, C., Loup-Escande, E., Lourdeaux, D., Thouvenin, I., & Valléry, G. (2020). User acceptance of virtual reality: an extended technology acceptance model. *International Journal of Human–Computer Interaction, 36*(11), 993-1007. https://doi.org/10.1080/10447318.2019.1708612

Wei, L., Shang, C., Chen, X., & Venkateswaran, N. (2022). The use of knowledge management-based information collaborative learning tool in english teaching Classroom. *Wireless Communications and Mobile Computing, 2022,* 1-10. https://doi.org/10.1155/2022/6367007

Zhang, S., Wen, Y., & Liu, Q. (2022). Exploring student teachers' social knowledge construction behaviors and collective agency in an online collaborative learning environment. *Interactive Learning Environments, 30*(3), 539-551. https://doi.org/10.1080/10494820.2019.1674880

Zurba, M., Petriello, M. A., Madge, C., McCarney, P., Bishop, B., McBeth, S., Denniston, M., Bodwitch, H., & Bailey, M. (2022). Learning from knowledge co-production research and practice in the twenty-first century: global lessons and what they mean for collaborative research in Nunatsiavut. *Sustainability Science, 17*(2), 449-467. https://doi.org/10.1007/s11625-021-00996-x