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A Usability and Acceptance Evaluation of the Use of Augmented Reality for Learning Atoms and Molecules Reaction by Primary School Female Students in Palestine

Ahmed Ewais[1,2] and Olga De Troyer[2]

Abstract

The chemical reaction between different molecules is an important learning subject in a chemistry course. Especially for elementary school students, this can be an abstract concept and therefore difficult to understand. One way to facilitate this learning process is to use Augmented Reality (AR) technology, which is considered as an added value compared with classical learning materials such as textbooks, two-dimensional images, video, and so forth. Among the different advantages of using AR technology in the context of the educational domain is the fact that three-dimensional technology is offering a safe environment especially if the students have to perform critical tasks such as simulating chemical reactions. This work investigates students' attitude toward the use of a mobile AR application for learning atoms' and molecules' reactions. In particular, we focused on female students because, in general, female students show less interest in science and technology than male students. We were keen to investigate whether the use of AR technology could change this

[1]Computer Science Department, Arab American University, Jenin, Palestine
[2]Web & Information System Engineering Laboratory, Department of Computer Science, Vrije Universiteit Brussel, Belgium

Corresponding Author:
Ahmed Ewais, Computer Science Department, Arab American University, P.O. Box 240, Jenin, 13 Zababdeh, Palestine.
Email: Ahmed.Ewais@vub.be

attitude. The students are able to interact with different AR components to explore the possible reactions in a three-dimensional interface, to understand the structure and shape of atoms and molecules, and to view related explanations in their native language, that is, the Arabic language. The mobile AR application was evaluated by a class of 12- to 13-year-old (7th grade) students in a Palestinian primary school. The number of participants was 50, all female students. After analyzing the results, we can conclude that these female students had a positive attitude toward the use of this AR application in their learning process.

Keywords
mobile, augmented reality, education, chemistry, usability

Introduction

Since the past two decades, Augmented Reality (AR) has been increasingly getting researchers' interest. The first use of AR applications was in the 1990s. It is believed that the term *Augmented Reality* was coined by Tom Caudell in 1990 (Lee, 2012). AR is defined as a technology that allows to give an overlay of computer-generated data on the user's view of the real environment (Azuma, 1997). AR uses virtual reality combined with video, images, audio, and so forth (Parker, 2011).

According to Azuma (1997), AR applications need to satisfy three important requirements. AR application should enable the user to interact with AR components in real time; it should combine virtual and real world together; and finally, AR application should register virtual and real object inside the devices' screen.

In general, there are two types of AR mobile-based applications: *marker-less AR application* and *marker-based AR application* (Lee, 2012). A marker-less application is mainly using the smartphone's global positioning system, compass, and accelerometer to determine the location of the device and triggers events based on the current location. Triggered events can be, for instance, displaying a three-dimensional (3D) object or playing an online video or audio. Marker-less AR applications are, for instance, used to display information about nearby museums, sights, libraries, and so forth. On the other hand, marker-based AR applications are using a target image like a Quick Respond to trigger events such as displaying virtual objects (two-dimensional [2D] or 3D) or playing video. In general, the camera identifies the markers resulting in presenting the corresponding virtual objects mapped to the markers on the screen of the device used (PC, tablet, or smartphone). Subsequently, the user can interact with the virtual object through the screen or by moving the marker itself.

Both types of AR applications got researchers' interest to investigate the use of AR in teaching and learning because of the various advantages that AR offers over the traditional media. AR is visually and interactively richer than classical learning materials (Lee, 2012). Accordingly, it is considered as more attractive and motivating than traditional learning materials (Azuma, 1997). For instance, AR can integrate different formats such as text, audiovisual materials, and 3D models into a real environment. Also, AR offers better way of learning by providing physical and virtual objects in a rich sensory context (Dunleavy, Dede, & Mitchell, 2009).

Some researchers (Freitas & Campos, 2008; Kerawalla, Luckin, Seljeflot, & Woolard, 2006) already reported comparative studies between traditional classes and classes that use AR technology, which confirmed that AR improves student learning. According to P. Chen, Liu, Cheng, and Huang (2017), in most cases when using AR for educational purposes, it was used in higher educational settings. Furthermore, among the different domains (social science, engineering, health, etc.) considered for the use of AR, the science domain is most common. This is related to the fact that AR is considered as an effective tool for learning concepts and topics that cannot easily be conducted in real world, for which there is a lack of special devices and hardware and because of the ability of visualizing abstract or complex concepts.

With the increased spread of smartphones and tablets, researchers also started investigating the use of such devices in different educational contexts (Akçayır & Akçayır, 2017; Farley et al., 2015). Furthermore, recent hardware technologies along with different software applications make it possible to run mobile-based AR applications.

This article presents a study on female students' attitudes toward the use of AR for learning chemistry at the primary school level. The focus is on female students because, in general, female students show less interest in science and technology than male students. In addition, a recent World Bank report (The World Bank, 2018) emphasizes the need to encourage female students to complete their 12 years of education as this can increase economic benefits. Furthermore, it is known that male students, in general, have a good experience with 3D games, Virtual Reality (VR), and AR (Cai, Wang, & Chiang, 2014; Johnson, Smith, Willis, Levine, & Haywood, 2011; Lee, 2012). In general, female students are less familiar with 3D games, VR, and AR. Therefore, it is quite important to specifically investigate female students' attitudes and motivation toward the use of AR technology in the learning process as a negative attitude may have a direct impact on their learning achievements. However, mobile-based AR applications are not limited to females or chemistry; they are broadly applicable in education.

This AR application demonstrates the concepts of atoms' and molecules' structure and molecules' reactions as given in the chemistry course. There are different reasons for the need to integrate new methods and techniques to learn and teach chemistry. First, for many primary school students, chemistry is not an easy course. Some concepts such as atoms, molecules, and chemical interaction are very abstract and therefore difficult to grasp. For instance, it is difficult for them to imagine how molecules can interact with each other and produce new chemical materials. Another important reason is related to the fact that there is a limitation in having different chemical resources for Palestinian schools due to high expenses and political issues. Another important reason is the safety issue that is related to doing experiments in the lab and may (accidently) result in a dangerous gas or flames. AR plays an important role to avoid such situations and provides students with a safe environment to experiment. Furthermore, AR can be used to represent molecules whose real counterparts are unavailable or expensive materials.

This article is structured as follows. The next section presents prior work related to investigating the use of AR in educations contexts. It is followed by "Research Methods" section that introduces our research method and the setup of the conducted evaluation. Then, the evaluation results are presented, which is followed by a discussion and recommendation in the succeeding section. The final section concludes this article with future work.

Literature Review

This section reviews the different studies exploring the use of AR technology in different domains and particularly in education. We start by presenting studies that are related to investigating both students' motivation and attitude toward the use of the AR technology in education. In addition, we also review studies that deal specifically with female students' attitude toward information and communication technology (ICT). Then, we present studies that were conducted to investigate the usability aspects of AR application.

In general, AR technology has been explored in different domains. For instance, games and entertainment use AR technology, and in Schrier (2006), it is mentioned that AR games can be considered as a fun, motivating, and engaging environments for students to learn different topics. Other research work (Freitas & Campos, 2008) indicated that using a SMART AR application is a good tool especially for weak students to gain knowledge about different learning concepts. The students were able to explore transportation, animals, and so forth using 3D models inside an AR computer-based application.

The use of AR applications has also been explored in different fields of science. In the study presented in Bressler and Bodzin (2013), secondary school students were able to play collaboratively an inquiry-based mobile AR game to show related information and to solve different detective cases. Another work (Kerawalla et al., 2006) presented a comparative study for 10-year-old children between using a mirror AR interface and traditional teaching methods to learn about the sun and earth. Unexpectedly, the results showed that the students who used AR technology were less engaged than those who used traditional learning resources. Therefore, a number of design requirements have been suggested such as enabling teacher to add learning content to the AR application. Also, AR has been used in mathematic courses (Bujak et al., 2013). Furthermore, a simulation for different laws of physics using AR has been proposed (Irawati, Hong, Kim, & Ko, 2008; Matsutomo, Miyauchi, Noguchi, & Yamashita, 2012).

In the context of chemistry education, a number of AR-based applications are proposed. For instance, Fjeld and Voegtli (2002) reported on an application using a tangible user interface for displaying atoms in 3D models with clearly visible nucleus and outermost valence shell. The proposed applications used table, projection screen, camera, booklet, cube with patterns in each surface, and gripper. The proposed application enabled users to interact with, rotate, and compose molecules, getting aural and visual feedback. Another AR solution for chemistry education is presented in Nuñez, Quirós, Nuñez, Carda, and Camahort (2008). The developed application helps university students to study the inorganic chemistry in term of materials and structures. Another reported research work (Tuli & Mantri, 2015) developed AR application that can be used in chemistry laboratory. The application used different 2D markers for each chemical in chemistry laboratory to show 3D object representing corresponding chemical. The developed application was also featured with speech recognition so that students can give voice command to move to next step in a chemical experiment. A recent work (Behmke et al., 2018) discussed the development, implementation, and assessment of mobile-based AR application that transformed 2D molecular representation into interactive 3D models. Furthermore, Zheng and Waller (2017) presented an AR application called *ChemPreview* that can be used to interact with a protein using natural hand gestures using specific AR glasses. More reviewed works in using AR in education are presented in Saidin, Halim, and Yahaya (2015).

In the educational context, both students' motivation and attitudes toward the use of ICT solutions are considered important aspects. Motivation is defined as the student's desire to engage in a learning environment (Keller & Litchfield, 2002). Because researchers started to investigate the use of AR technology in educational settings, a number of studies investigated the student's motivation toward the use of AR technology in learning as well as the students' learning achievements (Akçayır & Akçayır, 2017; Lin, Chen, & Chang, 2015). For instance, researchers observed that the students' reaction regarding reading an AR textbook by displaying related text, avatar, sound, and so forth was positive (Dünser & Hornecker, 2007); a high motivation was one of the important observations of the conducted evaluation. Another recent reported work (C. H. Chen, Huang, & Chou, 2017) showed that using an AR-based multidimensional concept map in elementary school can improve the students' learning achievements (the study included 65 students with an average age of 11 years). Moreover, the work in Akçayir, Akçayir, Pektaş, and Ocak (2016) investigates the students' laboratory skills and attitudes toward science laboratories. The conclusion was that AR technology helped students to build a positive attitude toward physics laboratories. Furthermore, the students' laboratory skills were improved by the use of different AR components such as animation, video, images, and 3D models. Another study (Nuñez et al., 2008) showed promising results concerning students' acceptance and academic achievements after using an AR application in learning chemistry course. The work presented in Taçgin, Uluçay, and Özüağ (2016) showed an AR mobile-based application using a head-mounted display to teach students periodic table and atomic structure of the elements and molecules. The results showed that the students' motivation was increased by means of natural hand motion manipulation and high fidelity of 3D visual designs. Also, a design-based research presented in Irwansyah, Yusuf, Farida, and Ramdhani (2018) showed an interesting potential for students to use the developed AR application in learning molecular geometry.

As this article focuses on female students' attitudes toward the use of AR technology in education, we also reviewed work related to the attitude of female students toward ICT in general, and AR in particular, in education. Some research (Kubiatko & Haláková, 2009; Végh et al., 2017) showed that males responded better than females concerning the use of ICT in educational context. Also, the results presented by some researchers (Kubiatko, 2011; Tondeur et al., 2016) showed that female students have less positive attitude toward computers and ICT in general. On the other hand, some researchers claimed that there is no significant difference between male and female students' attitudes toward the use of AR technology and ICT in general (Verma & Dahiya, 2016). For instance, in Sirakaya and Kiliç Çakmak (2018), it is mentioned that neither gender nor daily use of computers and smartphones could be considered as factors that affect the attitude toward the use of AR applications. Also, another study (Tondeur et al., 2016) showed that there is no significant different between females and males concerning their attitude toward computers for educational purposes.

In general, learning experience is directly related to usability (Cuendet, Bonnard, Do-Lenh, & Dillenbourg, 2013). As a result, different researchers performed usability studies related to AR applications. For instance, the study in Koong Lin, Hsieh, Wang, Sie, and Chang (2011) investigated usability aspects of an AR book which allows children to learn about fish conservation. The results showed that learners were interested in using AR technology because of the good usability results of the developed system. In Akçayır and Akçayır (2017), it is showed that an important challenge is the difficulty that users may experience to handle and interact with an AR application interface. Also, some researchers (Lin et al., 2015; Squire & Klopfer, 2007) showed that a usable interface is important to avoid technical problems, while the students are using an AR application. Moreover, in Yu, Jin, Luo, Lai, and Huang (2009), it is suggested that AR technologies need to optimize devices memory and need to be fast enough to display images, 3D models, audio, video, and so forth smoothly.

Research Methods

This section presents the research goal and the research question of our work. Next, the developed AR mobile application is presented, and the setup of the usability and acceptance evaluation is explained.

Research Goal and Research Question

The main goal of this study was to investigate female students' attitude toward the use of an AR mobile application in a chemistry course. Therefore, the research question was formulated as follows: *What is the student s attitude toward using an AR mobile application in a chemistry course for female students of a Palestinian primary school*?.

AR Application

To answer the research question, as a first step, a suitable AR mobile application was needed. For this purpose, an interview with the class teacher has been done to identify some of concepts that the students experience as difficult to learn. Molecule reaction was selected to be simulated using a mobile AR application. Therefore, the mobile AR application was developed to enable students to explore the different reactions between a number of atoms and molecules. It is important to mention that this AR application was only created for the purpose of evaluating both its usability and students' acceptance for using an AR application in their chemistry course. This implies that the functionality of the application is limited and does not cover all possible atoms, molecules, and interactions. The selected atoms and reactions were based on the advice of the chemistry teacher.

The 3D representation for each atom and molecule enables students to visualize and master the structure of the different components. For instance, the student is able to visualize atoms of Oxygen, Hydrogen, and water in a 3D representation. They are able to see that a water molecule is composed of one Oxygen atom and two Hydrogen atoms.

The mobile AR application was developed as a marker-based Android application using Unity3D and the Vuforia SDK. Unity3D was the game engine, while the Vuforia SDK was used for dealing with the AR aspects. The application reads special cards, that is, "markers," by using the camera of the smartphone. These markers are used to represent the following atoms: Oxygen, Zinc, Hydrogen, Sodium, Chlorine, and Copper; and two molecules: Ammonia and Hydrochloric. Each marker contains the name of the atom, its associated number from the periodic table, and a symbol or icon to represent it.

Once the marker is placed in the scope of the smartphone's camera and according to the used marker, a 3D object is displayed to represent the

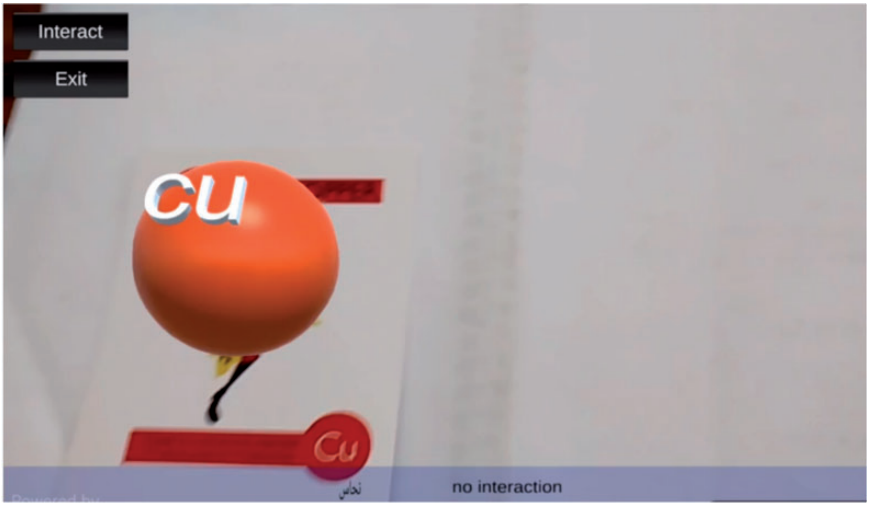

Figure 1. AR application displaying a Copper atom.

associated atom. Furthermore, an Arabic explanation is displayed about this atom. Figure 1 shows a marker and the 3D object representing Copper "Cu" with its name in Arabic language underneath.

The application is able to display the possible reaction between two atoms and will present the formed molecule as a 3D object. This is achieved by placing two markers close to each other in the scope of the smartphone's camera. Figure 2 displays such a situation with the atoms Na and Cl presented as 3D objects. Furthermore, a description about the possible interaction between both atoms is displayed in Arabic at the bottom of the image. If there is no possible reaction between the two atoms, a message will be displayed indicating that there is no interaction possible.

Once the student presses the interact button, the formed molecule will be displayed in a 3D representation and with an icon to symbolize the molecule. Figure 3 shows the 3D structure of salt molecule formed from Na and Cl, and it shows the icon for salt. Moreover, an Arabic explanation about salt is shown on the screen.

The application also enables the students to visualize molecules by using specific markers. For instance, Figure 4 shows two molecules—Ammonia and Hydrochloric—which form a new component called ammonium chloride.

The predefined reactions are the following: $H + O_2 = H_2O$ forming Water, $Cu + O_2 = Cu_2O$ forming Black Copper Oxide, $2Na + Cl = 2NaCl$ forming Salt, and $NH_3 + HCl = NH_4Cl$ forming Ammonium Chloride.

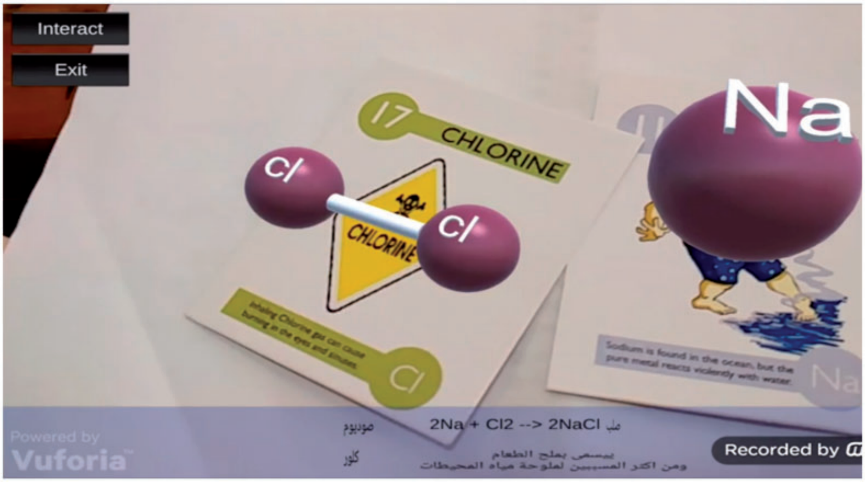

Figure 2. Two atoms and an explanation of their possible reaction.

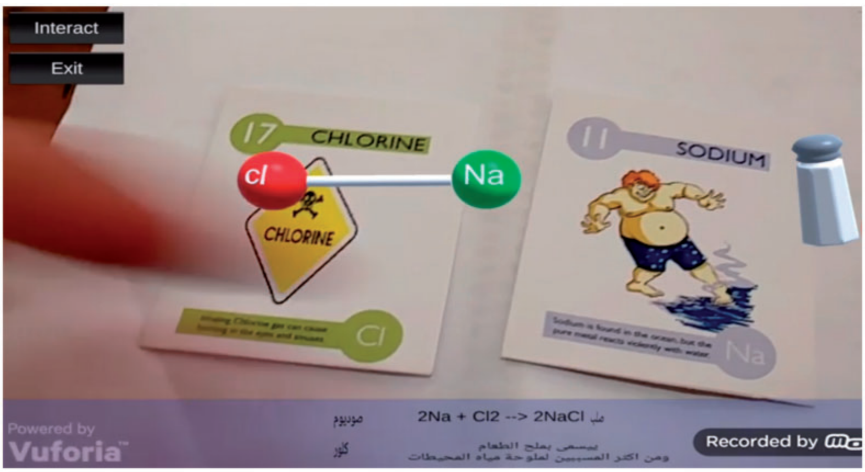

Figure 3. The result of an interaction.

Setup of the Validation

This study mainly focused on the usability and students' acceptance for using an AR-based learning application in a chemistry course. The evaluation was

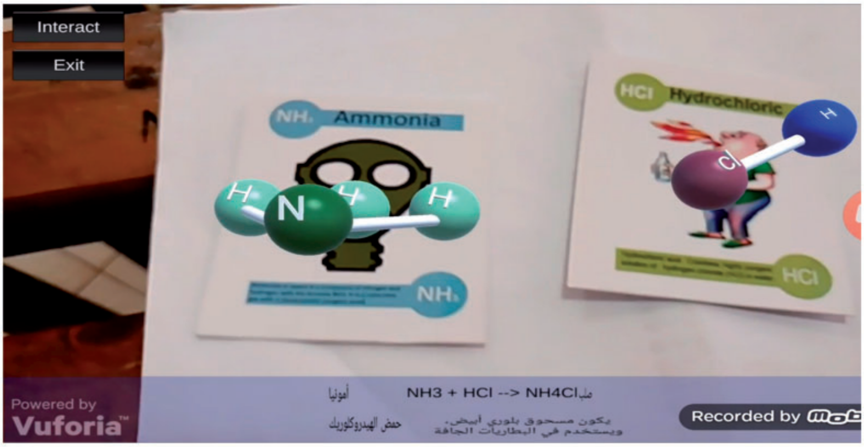

Figure 4. Two molecules and the possible interaction.

conducted in an academic setting inside a lab in a Palestinian school with a class of female students. The evaluation took place during a 1-hour session and consisted of three steps:

First step—introducing the AR application (10 minutes). We realize that using a mobile AR application may require some learning time. Therefore, we were not expecting that a student, even not one skilled in AR, could interact and work with the proposed application immediately. For this reason, they were given a short introductory session.

One of the researchers presented the mobile AR molecules reaction application to the students. He explained the markers and showed how they could be used with the mobile AR application. He showed what happens when the marker is inside the scope of the smartphone's camera. After that, he explained how the AR application shows a 3D representation for the recognized atom on the screen. Figure 5 shows a picture of this step. Moreover, he showed how the possible interaction between two atoms is presented: The name of molecule resulted from the interaction, the Arabic description about the atoms, the status of resulted molecules, the Arabic and English name of molecules, and a 3D representation of the resulted molecule. Figure 6 shows the interaction between two different atoms.

Second step—use of the application (10 minutes). The 50 students involved in the evaluation were asked to form groups of 5 students by themselves. As a result, there were 10 groups. A 10-minute slot time was given to the students to try the

Figure 5. Application demonstration.

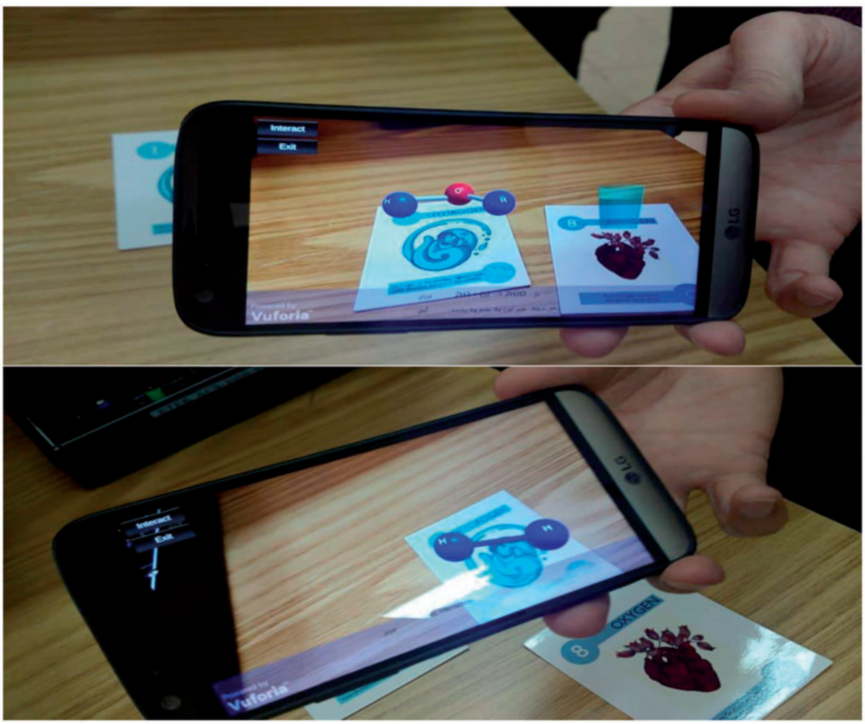

Figure 6. Learning with the mobile AR application.

application. Eight markers and a mobile device containing the application were given to each group. The students were asked to explore the application and try to find out how they can interact with markers using the AR application. Each group of students could interact, visualize, discuss, and learn without a teacher's direct instructions. They were able to see which atoms can interact with each other and their result.

Third step—questionnaire (15 minutes) and interviews (15 minutes). Questionnaires were distributed to all students, and they were asked to fill out the questionnaire. Students were able to contact their teacher in case they needed clarifications for a question. Afterward, the students were asked to volunteer for an interview. The 10 students who volunteered were interviewed using a number of predefined questions. More details about the design of paper-based questionnaire and the interview questions are given in "Questionnaire-Based Evaluation" section.

Participants

The evaluation was carried out with 50 female students of one Palestinian primary school in Jenin. The students were 12 to 13 years old and in a class of the 7th grade. They were all following a chemistry course. On purpose, we opted for these students because the application is intended for supporting students following a chemistry course. Female students were selected because of the research objective. It is important to mention that the students were not obligated to participate in the evaluation. This was done to have objective evaluations. Furthermore, they were informed that they would not be marked for the evaluation itself and that their responses were anonymous. More demographic detail about the participants is given in "Demographic Data" section.

Questionnaire-Based Evaluation

In this evaluation, a quantitative questionnaire was adopted to investigate the participants' attitudes toward the use of the AR application in the chemistry course. This was complemented with a qualitative questionnaire to delve deeper into the students' opinions and experiences. It is important to mention that all questions were in the Arabic language to avoid misunderstanding due to the language used.

This hybrid approach, combination of qualitative and quantitative methods, is used on one hand to obtain reliable and objective results (by using quantitative evaluation) and on the other hand to reveal subjective and important feedback concerning the mobile AR application (by using the qualitative questionnaire). Furthermore, by checking the consistency between results from both questionnaires, it was also possible to judge the validity of the evaluation results.

The quantitative questionnaire was used to be able to evaluate the mobile AR application's usability from the end users' perspectives. The System Usability

Scale (SUS; Brooke, 1996) was used. SUS can be used to measure usability, perceived usefulness, attitude, intention to use, and perceived ease of use; it has been used in different other studies related to AR (see, e.g., Koong Lin et al., 2011; Pérez-López & Contero, 2013). In particular, there were eight questions on usability, two on perceived usefulness, four on attitude, three on intention to use, and three on perceived ease of use. Each question was evaluated using a Likert-type scale (from 1 to 5). In the beginning of the evaluation form, general questions were used to gather information about the participants, such as their background in VR, AR, the use of 3D games, and the use of AR technology.

The qualitative questionnaire was used in the interviews. Students who volunteered for the interview were asked to answer six questions. The questions were adopted from Cai et al. (2014) and were selected and reviewed by an expert in software usability and the course teacher to ensure their validity. The questions were mainly used to encourage the students to express their opinions and feelings regarding the mobile AR application. This step has been conducted for two reasons: for digging deeper into students' feedback on the application and for checking the consistency of these students' responses in the quantitative questionnaire.

As we were looking for a critical and objective evaluation, we adopted a number of scientific approaches to avoid bias. First, the students were encouraged to be critical and objective. Next, to try to exclude bias, negative and positive formulated questions were used in the questionnaire. Any contradictory results led to disregarding that evaluation form. Furthermore, before distributing the questionnaire, it was mentioned that this evaluation was only aimed for measuring the students' attitudes toward the use of mobile AR application in a chemistry course. Moreover, they were informed that the evaluation results would give insights on the quality of the provided application and reveal advantages and disadvantages of such an application. It was also mentioned that there were no correct or wrong answers. They were also informed that the evaluation would be done anonymously so that there was no need to indicate their names or IDs on the questionnaire. Also, questions were formulated with care to avoid receiving more favorable answers from the participant (Lazar, Feng, & Hochheiser, 2010).

Data Analysis Principles

In the paper-based questionnaire, all answers were mandatory and on a scale from 1 (*strongly disagree*) to 5 (*strongly agree*). For each individual evaluation feedback on a positively formulated question, a score of 3 or higher is considered as "good" (positive feedback). Each individual evaluation feedback on a negatively formulated question is also considered "good" when the score is 3 or fewer (positive feedback).

A quantitative method was used to analyze the data obtained from the paper-based questionnaire. Descriptive statistic was performed for each statement, that is, minimum and maximum values, mean, and standard deviation.

Concerning the interpretation of the evaluation results, we have adopted the following protocol for each positively formulated statement:

1. Average values between 3.5 and 5 were considered as a good to perfect evaluation.
2. Average values between 2.5 and 3.5 were considered as a neutral evaluation.
3. Average values lower than 2.5 indicated a rather poor evaluation and suggested that improvements are required.

The aforementioned protocol was reversed for negatively formulated statements. Therefore, the less the average, the more positive results:

1. Average values between 1 and 2.5 were considered as a good to perfect evaluation.
2. Average values between 2.5 and 3.5 were considered as a neutral evaluation, and
3. Average values more than 3.5 indicated a rather poor evaluation and suggested that improvements are required.

Each statement was given a code to make it easier to refer to the statements. Eight statements were related to the usability and were given the following codes: USA1, USA2, USA3 ... USA8.

Evaluation Results

This section presents the evaluation results concerning the general information about the participants, the SUS questionnaire, and the interview.

Demographic Data

As mentioned earlier, the evaluation was conducted with a group of 50 students with almost homogeneous background about mobile AR applications. Table 1 (left side) shows that 68% (34) of the students already knew VR. However, the majority of the participants (30) had no or very little experience with AR. Such result is expected as AR technology is a relatively new trend.

In Table 1 (right side), we see that few participants 10% (5) mentioned that they play 3D games more than 3 times a week, whereas most of them 78% (39) stated that they play 3D games once a week. There are 8% (4) participants who indicated that they have never used 3D games. More than 35 participants stated that they used AR only once or never. Finally, 60% of the participants were not at all familiar with AR technology, and more than 70% of participants had never used AR technology or used it only once.

Usability and Students Attitudes

In general, the obtained results were positive. Table 2 provides an overview of the number of questions that were rated with good, neutral, and poor for the

Table 1. Students Demographic Data.

Question	Yes	No	Questions	>3 times	2–3 times	Once	Never
Do you know Virtual Reality?	68%	32%	How often do you use 3D games?	10%	4%	78%	8%
Do you Know Augmented Reality?	40%	60%	How often do you use AR applications?	18%	10%	2%	70%

Note. AR = Augmented Reality.

Table 2. Summary of the Quantitative Evaluation.

	Score			
Category	Good	Neutral	Poor	Total
Usability	6	2	0	8
Perceived usefulness	2	0	0	2
Attitude	3	1	0	4
Intension to use	2	1	0	3
Perceived ease of use	3	0	0	3
Total number of all questions				20

different categories. As shown in the provided table, no questions were rated as poor. Two questions for Usability, one for Attitude, and one for Intension to use received a neutral rating. All other questions, six for Usability, two for Perceived usefulness, three for Attitude, two for Intension to use, and three for Perceived ease of use, received a good evaluation.

More in detail for Usability, the three positively formulated questions received a good rating. Concerning the negatively formulated questions, there were three questions that received a good rating, while the other two questions were given neutral scores.

Next, we provide the details for each part of the questionnaire. To make it easy for the readers to distinguish between the positively formulated questions and negatively formulated questions, we added at the beginning of each negatively formulated question a star symbol (*) and put the question in italic.

A number of findings can be revealed from Table 3. For instance, question USA5 *(I would imagine that most people would learn to use this mobile AR application very quickly)* gained the highest average with second lowest standard deviation. This indicates that the mobile AR application can be easy to use.

Table 3. Usability Evaluation Results.

Code	Questions	Minimum	Maximum	Average	Standard Deviation
USA1	*1. *I found the mobile AR application unnecessarily complex*	1	4	1.72	0.68
USA2	*2. *I think that I would need the support of a technical person to be able to use this mobile AR application*	1	5	3.38	0.73
USA3	3. I found the various functions in this mobile AR application are well integrated	3	5	4.1	0.28
USA4	*4. *I thought there is too much inconsistency in this mobile AR application*	1	4	1.7	0.59
USA5	5. I would imagine that most people would learn to use this mobile AR application very quickly	2	5	4.32	0.36
USA6	*6. *I found the mobile AR application very cumbersome to use*	1	4	1.68	0.68
USA7	7. I felt very confident using the mobile AR application	2	5	4.18	0.37
USA8	*8. *I needed to learn a lot of things before I could get going with this mobile AR application*	1	5	3.38	0.66

Note. AR = Augmented Reality.

The rest of the questions that received good average scores were USA3 (*I found that the various functions in this mobile AR application are well integrated*) and USA7 (*I felt very confident using the mobile AR application*) for positively formulated questions and USA1 (*I found the mobile AR application unnecessarily complex*), USA4 (*I thought there is too much inconsistency in this mobile AR application*), and USA6 (*I found the mobile AR application very cumbersome to use*) for negatively formulated questions. Such results indicated that the AR application in general has good usability characteristics, such as easy to use, attractive, and well integrated.

Two questions were given a neutral score, that is, USA2 (*I think that I would need the support of a technical person*) and USA8 (*I needed to learn a lot of things before I could get going with this mobile AR application*). The standard deviations are relatively high for both questions. This result is expected as most of the participants had not yet used an AR application. However, this issue can be solved by providing a proper introductory session for the students in the chemistry class or by providing them with a manual on how to use the mobile AR application.

Table 4. Perceived Usefulness Evaluation Results

Code	Questions	Minimum	Maximum	Average	Standard Deviation
PU1	9. I paid more attention in this class than any others	1	5	3.76	0.37
PU2	10. This class has been useful and interesting	1	5	4.24	0.451

Table 5. Students' Attitude Evaluation Result

Code	Question	Category	Minimum	Maximum	Average	Standard Deviation
ATT1	11. I would like to take more classes like this	Attitude	1	5	4.22	0.4
ATT2	12. It is easier to follow the teacher's explanation in this type of classes	Attitude	1	5	3.28	0.69
ATT3	13. I behaved better in today's class than I did in other classes	Attitude	2	5	3.96	0.38
ATT4	14. I believe this AR material will help me pass the exam	Attitude	2	5	4.32	0.42

Note. AR = Augmented Reality.

Concerning the questions related to the perceived usefulness, the results (see Table 4) show an increase in perceived attention (PU1), and the students considered the class as interesting and useful (PU2). This result corresponds with results obtained in previous research such as Wojciechowski and Cellary (2013).

Concerning students' attitudes, the students mentioned that they behaved better in this class and that they would like to attend more classes that use AR technology. The majority of the students found that the use of AR technology could help them to pass their exams. However, this finding still needs further investigation by comparing students' results in exams with and without using AR technology during the course.

Table 5 shows the results of the questions related to the attitude aspect. The rating of question ATT2 (*It is easier to follow the teacher's explanation in this type of classes*) was neutral. This could be due to the fact that some of the students were too curious to experiment with the tool instead of focusing on the teacher‘s instructions. The students were also curious to know how a mobile AR application works and to explore the different markers, the functionalities, and so forth.

These findings echo those reported in the literature which also stated that using AR technology in education has a potential to improve students' attitudes and increase their motivation (C. H. Chen et al., 2017; Hwang, Wu, & Kuo, 2013; Lin et al., 2015). However, some researchers (Akçayır & Akçayır, 2017; El Sayed, Zayed, & Sharawy, 2011) attribute this effect to the so-called novelty effect, and this means that the effect would only be temporally. In other words, once the student gets familiar with the use of AR technology, the effect on his attitude and motivation might diminish.

With regard to students' intension to use AR technology, the results showed that the majority of the students like to use the mobile AR application for learning chemistry. As evidenced by the results on question ITU1 and ITU3, students are willing to use the mobile AR application at home and on a frequent basis. Table 6 shows the results of the questions that are related to the intension to use part of the questionnaire.

Concerning the perceived ease of use aspect, high average scores were obtained. Table 7 presents the results of the questions related to perceived ease of use. This is a good indication that the students found the mobile AR application easy to use and learn.

Table 6. Intension to Use Evaluation Result.

Code	Question	Minimum	Maximum	Average	Standard Deviation
ITU1	15. I would like to use this AR material at home	1	5	3.64	0.73
ITU2	*16. *I prefer the classic book over the new materials*	1	5	2.38	0.97
ITU3	17. I think that I would like to use this AR technology frequently	1	5	3.82	0.39

Note. AR = Augmented Reality.

Table 7. Perceived Ease of Use Evaluation Result.

Code	Question	Minimum	Maximum	Average	Standard Deviation
PEOU1	*18. *It was not easy for me to use the AR markers*	1	5	1.98	0.78
PEOU2	19. This AR material has been easy to learn and use	2	5	4.18	0.37
PEOU3	20. I think the AR mobile application is easy to use	2	5	4.38	0.31

Note. AR = Augmented Reality.

Interview Results

As mentioned earlier, after filling out the questionnaire, 10 volunteered students were interviewed. The results for each question were as follows:

All 10 students answered the question *What do you think about using an AR tool for learning molecules interaction?* with positive feedback and with some notable appreciation for the use of AR in the chemistry course. Among the different comments, one student stated: "It was an interesting experience for me to use an AR application in this activity." Another comment was "AR make it easier to visualize atoms and molecules structure than classical books." Other comments (4) were related to the idea of using AR technology to encourage students who have some difficulties to learn chemistry. Some students (4) mentioned to be eager to use AR more in the future classes. Such results confirmed that the visualization features of AR applications can play an important role in learning for students of this age (Martin & Loomis, 2012).

The answers on the question *Why do you think this tool is helpful? In what other classes could the tool help you?* indicate also a great appreciation for the value that AR adds to the learning activities in a chemistry course. A number of participants (5) were convinced that AR makes it easy, not only to understand the structure of atoms and molecules but also to understand the result of the interaction between atoms or molecules, by using markers and 3D representations. Others (3) think that a mobile AR application makes learning materials more interesting and concrete, which helps them to remember the material more easily. Such results confirmed outcomes of other related work such as Chiang, Yang, and Hwang (2014). Concerning the second part of the question, courses such as games, physics, human anatomy, and mathematics were named.

Ten answers concerning the question *Do you wish to use the mobile AR application to learn chemistry in the future? Why?* were all positive. Some of the participants (6) mentioned that the application should be available of the smartphone of the students so that they can discuss and learn as a group even after class time. Three participants mentioned that using AR for learning chemistry makes it an easy, interesting, and entertaining experience. Similar students answers are also found in the literature (see, for instance, Akçayır & Akçayır, 2017).

In reply to the question *Do you prefer to use the AR application on a smartphone or on a personal computer using a mouse to interact with the application*? eight participants indicated a desire to use it on a smartphone rather than on a personal computer, as a smartphone can be use everywhere and anytime. However, the other two students mentioned that with the small screen of a smartphone, it is not always easy to read the text.

Furthermore, participants were encouraged to state what they did not like about the application. The question was formulated as follows: *Do you think that the mobile AR application has disadvantages? What are they?* Some participants (2) answered this question with the earlier mentioned comment about the

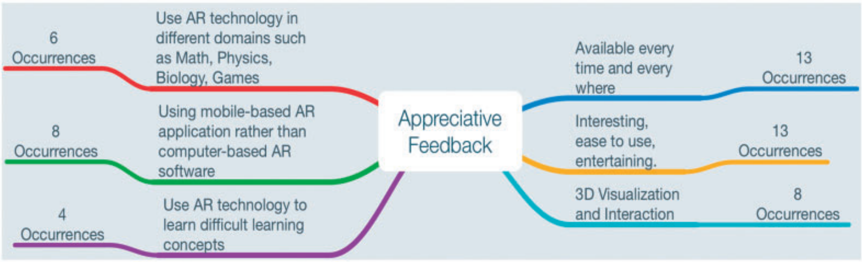

Figure 7. Categories of appreciative feedback and number of occurrences.
AR = Augmented Reality.

small screen size of a smartphone. Other participants (4) thought that there is a need to add more details about atoms, molecules, and interactions. The level of detail given should depend on the level of the student (beginner, intermediate, or advanced student). Other participants (3) answered this question with the suggestion of using the mobile AR application as a game instead of focusing on learning about atoms, molecules, and interaction. One student preferred to use a markerless AR application rather than a marker-based one.

Finally, students were asked the question *Can you offer some advice for improving this AR learning tool?* and two students indicated that the use of the periodic table as a marker could be better than having a marker for each atom. Four other participants suggested to create more markers so that they could explore all atoms in the periodic table during the evaluation. One student suggested to have exercises that can be performed using the AR application. The same student suggested to integrate the circumstances in which the interaction can happen between different atoms or molecules using animation and text. A number of suggestions (3) pointed to the need to add more textual information about each atom and molecules.

To summarize the obtained qualitative feedback, we can divide it into three categories: Appreciation, Depreciation, and Recommendation. Figures 7 to 9 summarize the qualitative feedback by showing for each category the number of times that a feedback has been mentioned during the interview. This number can be more than the number of participants (10) as it may be obtained from different questions and different students.

Discussion and Recommendations

The overall results of the conducted evaluation were quite positive. Usability was rated well despite the fact that most of the participants lacked a minimum experience with mobile AR applications, and there was no true training period

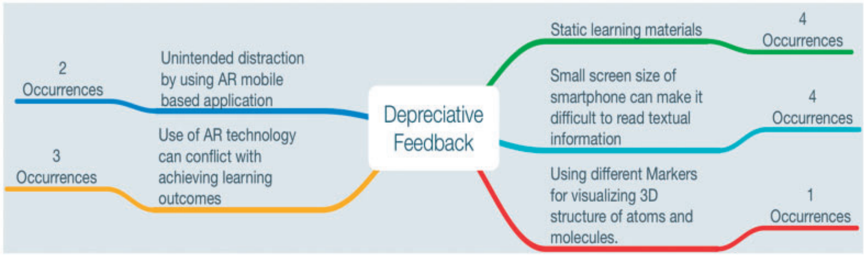

Figure 8. Categories of depreciated feedback and number of occurrences.
AR = Augmented Reality.

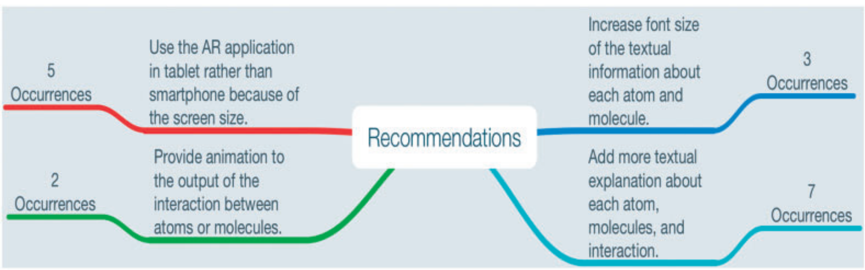

Figure 9. Categories of provided recommendation and number of occurrences.

foreseen to enable students to get acquainted with the use of AR. Furthermore, students had a positive attitude toward the use of AR in learning chemistry.

From the results presented in "Usability and Students Attitudes" and "Interview Results" sections, we can conclude that the mobile AR application has advantages over traditional learning materials as the application allowed participants to explore and visualize the atoms and molecules structure and explore the different possible interactions between the provided atoms and molecules without being AR expert. This result provides a first indication that such an AR application can be used in a chemistry course for elementary school students in Palestine, and more in particular for female students.

In general, the results from the qualitative evaluation are consistent with the results of the quantitative evaluation. The following points show that the consistency and validity of the conducted evaluation is good:

1. In the quantitative evaluation, the participants perceived the AR application as useful and easy to use. This is also confirmed in the qualitative feedback

by the fact that the interviewees were considering mobile AR applications as interesting, easy to use, and entertaining. Furthermore, other comments mentioned the usefulness of 3D visualization and the interaction with 3D models.
2. Good appreciation results for both attitudes and intension to use were confirmed in the qualitative evaluation by the fact that the interviewees were considering AR as a good tool for understanding atoms, molecules, and interactions. Furthermore, its use was suggested in different other courses such as math and physics.
3. There was a high appreciation of using AR over traditional materials. This is also confirmed by participants in the qualitative evaluation. They mentioned that it would be beneficial to provide them with mobile AR applications for different courses.

However, both quantitative and qualitative results raised some issues for which we have sought some explanations:

Unintended Distraction

The neutral score on question ATT2 *It is easier to follow the teacher's explanation in this type of classes* and based on qualitative feedback from participants about focusing on learning process instead of playing around with the different markers and AR mobile application gives an indication that the students were so excited to try the AR application that as a result, most of them were focusing on the use of the new technology rather than focusing on the learning process itself. On one hand, this confirms that curiosity is an important driving factor toward motivation and attitudes, but on the other hand, it could hamper the learning process (Pérez-López & Contero, 2013).

Ease to Use

A conflict was found between the answers of the questions USA5 *I would imagine that most people would learn to use this system very quickly* (which was rated with good) and the answers of the two questions USA2 *I think that I would need the support of a technical person to be able to use this mobile AR application* and USA8 *I needed to learn a lot of things before I could get going with this mobile AR application* (which were rated neutral). This can be as a result of the fact that most of the participants were non-AR users. Therefore, they were not aware of the need of using markers for this AR application. This remark has been raised also in the literature (Lin et al., 2015; Squire & Klopfer, 2007). This remark is also derived from the comments given during the interviews about using AR application without markers.

How to Use Feedback

During exploring the different interactions between atoms and molecules, the need for putting two markers close to each other in the scope of the camera was denoted. Some of the students were not able to realize this. Accordingly, some frustration was reported. However, such frustration can be avoided with careful observation and proper teacher guidance. It can be also avoided by displaying "how to use" hints which could ask the student to bring another atom or molecule marker beside the current marker so that a possible interaction can be simulated. Providing support to avoid technical problems was also raised in Akçayır and Akçayır (2017).

The results of the conducted evaluation, together with reviewed work (Akçayır & Akçayır, 2017; Cuendet et al., 2013; Kerawalla et al., 2006), have enabled us to formulate the following design recommendations for future mobile-based AR applications for helping students understanding atoms and molecules structures and interactions:

- Using the periodic table as marker for atoms can be useful. This will decrease the time needed to search for the required atom marker between the different available cards.
- Using AR technology with mobile phones leads to the fact that the use of text, images, audio, video, and animation inside the AR application should be considered with care. Learning content can overwhelm students, as the screen size is relatively small compared with tablets or PCs.
- Showing the different stages of the interaction between atoms or molecules could be provided with textual or audio information, and animations or 3D simulations. This can increase the level of details to be provided.

Conclusion, Limitation, and Future Work

From this research, we can conclude that AR technology provides different advantages over classical learning material. This study is useful for policy makers in the educational sector in Palestine. Our research work provides a first evidence for the potential of AR technology in Palestinian elementary schools, and more in particular for chemistry courses. It can help 12- to 13-year-old (7th grade) students to understand the structure of the atoms, molecules, and possible interactions between different atoms and molecules.

We admit that learning effectiveness was not considered in this study. Although the majority of the female students found that the use of AR technology could help them to pass their exams, further evaluations are required to determine the effectiveness of the use of AR technology in a chemistry course. Among the different factors that is related to the learning effectiveness is that students' learning outcomes can be affected by interaction with learning materials. Researchers report that increased interaction with learning materials can positively affect intended learning outcomes (Fulantelli, Taibi, & Arrigo, 2015; Lin et al., 2015). Other studies (Akçayir et al., 2016; Cai et al., 2014), which are related to examining students' performance after using AR technology in their classes, showed that students achievements were enhanced by using AR applications.

This study has a number of limitations. As mentioned, the intension of measuring the influence of the mobile AR application on the learning process itself was not in the scope of this study. In other words, future work will be needed to examine the effectiveness of the use of AR technology in respect with knowledge retention, acquired skills, and so forth. This can be done by means of a pretest and posttest or by comparing an experimental group with a control group. This is planned for future work. Furthermore, the study was done in only one school and in one class, and the number of participants was limited to 50. More studies will be needed to confirm the results of this study.

We also intend to conduct a study with school teachers to allow them to give their feedback on the effectiveness of using AR technology as a teaching tool inside chemistry course in Palestinian universities. We know relatively little about the attitude and acceptance of primary school teachers for using AR technology into their lessons.

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ORCID iD

Ahmed Ewais https://orcid.org/0000-0003-0035-9374

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Author Biographies

Ahmed Ewais earned his bachelor degree in computer science from Arab American University, Palestine in 2004 and master's degree in computer science from Vrije Universiteit Brussel, Belgium in 2008, where he also obtained his PhD in 2014. His PhD topic was Authoring Adaptive 3D Virtual Learning Environments, which aimed at supporting novice educators in the development process of adaptive 3D Virtual Learning Environments. He is a member of the Web & Information System Engineering Laboratory from September 2008 till now. He has been working as an assistant professor in Arab American University since 2014. He received different research funds and funding for research visits. He publishes in journals as well as in conferences proceedings. His interests are located in E-learning, Massive Open Online Courses (MOOCs), Virtual Reality, Augmented Reality, Human Computer Interaction, User Experience and User Interface, and Usability Evaluation. More information is available on https://wise.vub.ac.be/ahmed-ewais

Olga De Troyer is a full professor in computer science at Vrije Universiteit Brussel in Brussels, Belgium. She holds a master's degree in mathematics and a PhD in computer science. She has more than 30 years of experience in research in conceptual modeling and design methods for innovative information systems, applied to different areas such as databases, web systems, semantic web, software variability, E-learning, mobile applications, virtual reality, and serious games. She is the head of the research group Web & Information System Engineering, which she founded in 1998, where one of the foci is on new human–computer interaction aspects, including VR, AR, data physicalisation, as well as multimodal and multitouch interaction. Development of new engineering methodologies, authoring tools, and software frameworks for the rapid prototyping and efficient realization of innovative information environments is at the kernel of the research. Usability of the tools and environments that are developed is a constant concern. More information is available on https://wise.vub.ac.be/olga-de-troyer