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Designing and Developing an Augmented Reality Application: A Sample of Chemistry Education

Zeynep TAÇGIN[1], Nazlıcan ULUÇAY[2], Ersin ÖZÜAĞ* [3,4]
[1]Marmara University Distance Education Center & Social Science Vocational School
[2]Kocaeli University, Faculty of Arts and Sciences, Department of Chemistry
[3]Nihilio Vision Corp., [4] Kocaeli University, Laboratory of Image and Signal Processing (KULİS)

Abstract: Augmented Reality has been accepted as an effective educational method and this review depends on philosophical background of cognitive science. This means, several channels –aural, visual, and interactivity, *etc.* - have been used to offer information in order to support individual learning styles. In this study, Natural User Interface- and Human Computer Interaction-based Augmented Reality application has been developed for the chemistry education. The purpose of this study is to design and develop a student-centered Augmented Reality environment to teach periodic table, and atomic structure of the elements and molecules. Head Mounted Display has been used to develop Augmented Reality system, and user control has been executed with hand motions (grab, drag, drop, select and rotate). The hand motion control has been used to improve spatial abilities of students in order to maximize the transferred knowledge. Use of the most common natural controlling tools (fingers and hands) to interact with virtual objects instead of AR markers or other tools provides a more interactive, holistic, social and effective learning environment that authentically reflects the world around them. In this way, learners have an active role, and are not just passive receptors. Correspondingly, the developed NUI-based system has been constructed as design-based research and developed by using instructional design methods and principles to get reach of more effective and productive learning material. Features of this developed material consist of some fundamental components to create more intuitive and conductive tools in order to support Real World collaboration.

Keywords: Augmented reality, chemistry education, material development, instructional design, human computer interaction, natural user interface.

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* Contact the author:
e-mail: ozuag@nihiliovision.com
Phone:+90 262 303 33 92
Address: Kocaeli University Umuttepe Campus, Engineering Fac. Elec. And Telecomm. Eng. Dept., 41380 Kocaeli, TURKEY.

INTRODUCTION

The developed technologies are integrated to the education in order to support interactivity and experimentation of the students. From this point of view, scale of education technologies has been expanded to change the direction and presentation of information (Singhal, Bagga, Goyal, & Saxena, 2012). Nowadays, Augmented Reality (AR) and Virtual Reality (VR) applications have an enormous popularity and significance with offered opportunities in concern with offering information to the sensory channels of individuals.

AR removes individuals from actual reality by affecting perception and simply evokes the feeling of reality, and supports enhanced and facilitated plugins to perceive the RW (Taçgın & Arslan, 2016). AR mainly consists of virtual factors that are generated by the computer and augment the RW with virtual components (Ma & Choi, 2007; Maier, Tönnis, & Klinker, 2009; Yuen, Yaoyuneyong, & Johnson, 2011). The fundamental features of AR have been claimed by Azuma *et al.* (2001) as follows:

- Combines real and virtual issues in real environment,
- Includes real-time activities,
- Is registered in 3D components.

As known, reality concepts could be changed between the perceived physical and the virtual components. According to Milgram's "Reality Continuum" (1994), all points between the physical and virtual realities have been called mixed reality. This system could be imagined like a slider – between 0 and 1- structure. AR systems- sub category of mixed reality- are integrated and built on concepts that are specific to one service (Stirbu, Murphy, & You, 2012). According to research by Di Serio, Ibáñez, and Kloos (2013), shared features of AR and VR such as immersion, navigation and interaction can be derived from Azuma's AR properties (Azuma, 1997).

As understood, AR could be created by utilizing and connecting various innovative technologies (*e.g.*, mobile devices, wearable computers, and immersion technologies) (Wu, Lee, Chang, & Liang, 2013). Dunleavy and Dede (2014) mentioned two available forms of AR: (1) location-aware and (2) vision-based. Location-aware AR consists of enabled GPS services on mobile device. Moreover, mobile device integration of AR has increased its usability and popularity (Stirbu *et al.*, 2012). To utilize the location-aware AR applications on a mobile device or smartphone, the phone must be equipped with several necessary tools: (1) GPS technology, (2) an accelerometer, and (3) digital compass (magnetometer) (Yuen *et al.*, 2011). Vision-based AR presents digital media such as Quick Response (QR) code or two-dimensional (2D) target, and is used with camera of the mobile device.

These applications mostly have artificial user interfaces (keyboard, mouse, AR markers, *etc*.) to manipulate virtual objects. For instance, using a mouse is restricted to 2D, and it has to be mapped to the three-dimensional (3D) virtual environment. Thus, the user has to pay attention to the mental 3D mapping (Maier & Klinker, 2013).

On the other side, the basic procedure of AR technology is: calculate the affine transformation of virtual model to camera plane, according to the location of the camera and marker information in the real world. Then, draw the virtual model on the basis of affine transformation matrix. Finally, combine the video of real world and virtual model, displayed on the terminal display (Singhal *et al.*, 2012). According to Maier *et al.* (2009) and Yuen *et al.* (2011), the virtual objects can be rendered, such that they fit exactly to the real world image. Combining these images, AR generates an impression of the real world. For AR, this procedure has to be performed in real-time, such that a user can interact with real objects and camera without losing the 3D connection to the virtual object. In many AR applications, marker based approaches solve the alignment problem of the virtual data and the real environment by using visual markers such as 2D barcodes detectable with computer vision methods. This technique requires camera tracking in order to define positions of the real objects to the computer. The tracking systems get the data via using marker of the tracker system that takes a picture with webcam and tries to find special patterns of represented markers. Thus, position and rotation of the marker relative to the webcam have been calculated with computer vision algorithms.

With mobile devices or wearable computers, users can access knowledge from anywhere. Also, users can overlay the information as 3D in the Real World (RW), manipulate and examine real objects, and simultaneously receive additional information or execute the given tasks via hand motions (Maier *et al*., 2009). In addition to the 2D and 3D objects, digital assets - audio and video files, textual information, and even olfactory- and tactical information can be incorporated into perceptions of users in the RW. Collectively, these argumentations have been used to augment the learning environment in order to support comprehension of individuals via multiple stimuli (Yuen *et al*., 2011). From this point of view, AR and VR are used to enhance learning environment and there are many design principles that change features of the targets. Besides, the capability of AR has to be determined to reach at a suitable instructional design.

AR has potential to engage, stimulate and motivate students (Di Serio *et al*., 2013; Lin, Duh, Li, Wang, & Tsai, 2013). Research results show that AR has positive effects especially on motivation of the students, and supports attention (Di Serio *et al*., 2013). Moreover, AR could provide enhanced learning environment, and supports the situated and constructivist learning theory (Dunleavy & Dede, 2014) with creating active learning environment. Furthermore, AR systems may be used by multiple users at the same time. This provides opportunity for collaborative applications like engineering design, architecture, multi-user games, and education, among others (Singhal *et al*., 2012). Similarly, the study by Lin *et al*. (2013) indicates the relationship between AR and collaborative learning. Also, the results show that AR positively supports knowledge construction process of the students.

On the other side, because of the sophisticated structure of AR, students could be cognitively overloaded by the large amount of information they encounter, the multiple technological devices they are required to use, and the complex tasks they have to accomplish (Wu *et al*., 2013). For this reason, the instructional design (ID) method selection and application have to be executed by the instructional designers. Besides, the ID method selection depends on the educational need analysis that is the initial step of ID (Beetham & Sharpe, 2013; Raspopovic, Cvetanovic, & Jankulovic, 2016; Wegener & Leimeister, 2012). The result of analysis indicates necessities of the environment, and it is used to choose the learning principle, method and techniques. The capability of AR technology is generally used to learn practical experience with high quality visual components to explain tangible concepts. This means that the components have to be chosen carefully to attain the planned learning outcomes. And the actors of ID - administrators, technicians, designers, teachers and learners– need cooperation between themselves to create an effective learning environment.

AR has been used for educational purposes in spite of the stated and unstated impacts. Examples of AR applications, technologies, features and affordances in the education field have been provided in Table 1.

Table 1. A Summary of AR applications in Education. (Di Serio *et al*., 2013).

Research	AR technology employed	Most relevant features	Learning affordances
Dünser, Steinbügl, Kaufmann, and Glück (2006)	Stylus tracked with 6Do. Head Mounted Display (HMD).	Immersion. Interaction.	Spatial ability. Collaboration. Motivation.
Gutiérrez *et al*. (2010)	Fiducial markers. PC. webcam Interaction.	Interaction. Navigation.	Spatial ability.
Maier, Tönnis, and Klinker (2009)	Fiducial markers. PC. webcam Interaction.	Interaction. Navigation.	Experiential learning. Spatial ability.
Klopfer and Squire (2008)	Handheld devices. Navigation.	Navigation. Immersion.	Collaboration. Motivation.
Nilsson, Johansson, and Jönsson (2010)	HMD. Marker Tracking.	Immersion. Navigation.	Collaboration.
Chien *et al*. (2010).	Fiducial markers. PC. webcam Interaction	Interaction. Navigation.	Spatial ability. Support to memory cognitive processes.
Henderson *et al*. (2011)	Custom built stereo VST HWD. 10 tracking cameras.	Immersion. Navigation. Interaction.	Experiential learning. Kinesthetic learning.
Sumadio *et al*. (2010)	Fiducial markers. PC. webcam Navigation.	Navigation. Interaction.	Experiential learning. Motivation.

Experimental learning is one of the significant parts of science teaching in order to develop and train the scientific literacy of students. Experiments promote and enhance the process of scientific inquiry skills so as to strengthen the students' ability to understand and solve problems (Singhal *et al*., 2012). As seen in Table 1, AR is a learning technique to reinforce experimental and kinesthetic learning thanks to spatial ability.

The literature highlights that majority of students have problems to learn and understand the intangible concepts of chemistry (Kozma & Russell, 1997; Mahaffy, 2015; Thiele & Treagust, 1991; Wu *et al*., 2013). Besides, understanding chemistry depends on understanding the spatial structure of the chemical parts (Maier *et al*., 2009; Singhal *et al*., 2012). On the other hand, 2D visual objects have generally been used to teach concepts instead of 3D visual objects. According to Maier *et al*. (2009), there are several programs to visualize the molecules in 3D on a 2D screen but interactive schemes for rotating or moving the 3D objects are not intuitive. Accordingly, AR offers practical solution to this restriction so students can manipulate the virtual 3D objects in the computer. Correspondingly, it is possible to say that AR has a potential to improve understanding of the spatial structure of the molecule (Maier *et al*., 2009). The Augmented Chemistry provides an efficient way for designing and interacting with molecules to understand the spatial relations between molecules. For students, it is very informative to see actual representation of molecules in the 3D environment, inspect molecules from multiple viewpoints, and control the interaction of molecules (Singhal *et al*., 2012).

In the light of what mentioned above, the purpose of this study is to demonstrate the designing and development process, tools and other components of the AR application in accordance with the instructional design principles. In this project, the AR application has been developed to support comprehension and learning capabilities of students about the chemistry field. Correspondingly, the cooperative and individual-based learning approaches have been used to support social and cognitive abilities of the students. In this project, the periodic table subject of chemistry education has been chosen as an example, and educational scenario (storyboard) of the material has been developed by the subject expert.

METHODOLOGY

This study has been organized with respect to the design-based research paradigm. The purpose of the design-based research is to offer the relationship between theory-design-implementation through embodying the principles about teaching and learning (Barab, 2006; Barab & Squire, 2004; Cengizhan, 2007). Design-based research labors to generate and advance a specific set of theoretical constructs that generated, selected, or refined transcends the environmental particulars of the contexts. This focus on advancing theory grounded in naturalistic contexts sets design-based research apart from laboratory experiments or evaluation research (Barab & Squire, 2004).

On the other side, according to Hoadley (2004), design-based research has been separated from experimental research in several points: (1) it involves a tight relationship between researchers and teachers or implementers, (2) distinction is the use of tentative generalization- results are shared without the expectation that universality will hold, (3) the researcher frequently follows new revelations where they lead, tweaking both the intervention and the measurement as the research progresses and, (4) the researcher treats enacted interventions as an outcome, often documents what has been designed, the rationale for this design, and the changing understanding over time of both implementers and researchers of how a particular enactment embodies or does not embody the hypothesis that is to be tested.

THE PROJECT

The project team

The design-based research specialists have to be experts in their field, and the team has to consist of instructional designers. Also, the close cooperation between the project team members is a must throughout the process (Vanderhoven, Schellens, Vanderlinde, & Valcke, 2015). Thus, the quantities, roles and tasks of the team members have been provided in Table 2.

Table 2. The Roles and Duties of the Project Team

Role	*f*	Duties
AR visual designer	2	Designing and developing the sample screens Integrating the knowledge to the sample screens in accordance with the ID principles Designing, editing and integrating the medias Developing the animations and simulations Adding the transactions between the screens Creating and adding instruction Testing the material periodically and revising it through the feedback
AR coder	1	Coding hand tracking to transfer the hand motions to the virtual environment Coding the interaction and reactions of virtual objects Coding the responses in accordance with the rules and interaction
Instructional designer	1	Determining the suitable learning theories Evaluating the visual components and giving feedback
Subject expert	1	Analyzing the education need and determining the abilities of target Analyzing the knowledge Organizing the knowledge through the determined learning methods and techniques Determining the measurement and evaluation methods Providing the visual and audial components via studio records Matching the media with subjects Testing the material periodically and revising it through the feedback

Brief description of the project

The project consists of a chemistry education scenario that is designed by the instructional designer and subject expert, to support students with regards to their knowledge of the periodic table. As known, the students face several restrictions to understand the intangible concepts of chemistry. A great number of supplementary learning materials have been developed to handle these restrictions. However, students need well-designed materials to reach at the expected learning outcomes. From this point of view, components of the designed materials have to be defined in accordance with the student needs, and the ID process has to be applied correctly by the project team. Design and development processes have a cycling structure between the team members in accordance with the design-based research phases.

Learning process of the human brain is related with the active sense quantification. This means that presentation ways of the knowledge have to contain multiple components: audio, text, visual, and interaction. As mentioned above, AR has the paramount potential to offer multiple information, and it is also a suitable method for experimental teaching. Thus, this supplementary material of chemistry education has been designed and developed by using the AR technology. This Human Computer Interaction (HCI) based project has been developed with the Unity3D and Maya3D software. Also, the project has been developed as a Natural User Interface (NUI) that is an emerging computer interaction methodology. NUI focuses on human abilities such as touch, vision, voice, motion and higher cognitive functions such as expression, perception and recall. NUI seeks wider breadth of communication modalities that leverage skills people gain through traditional physical interaction (Liu, 2010).

In this project, users could interact and manipulate -touch, grab, move, visualize- the virtual 3D objects, which are presented via HMD through physical hand motions. According to Chen, (2006) as well as Liu et al., (2007), allowing users to use hands in a direct manipulation with objects provides experimental, collaborative and interactive learning environment. Figure 1 shows an example setup of developed AR environment.

Figure 1. An Example View of the Developed AR Environment.

As seen in Fig. 1, the RW has been augmented with the placed virtual objects, and hand motions of the users have been tracked to the interaction via the developed software. Fingers of the users have been defined as a pointer for element selection from the periodic table. This way, the virtual objects could be grabbed via physical hand motions.

Target audience

Target of this study has been considered as the K12 level chemistry students.

Goals

This project aims to offer a constructivist and cooperative learning environment for chemistry students. The high fidelity visuals, audios and other multimedia components have been designed in accordance with the learners' abilities. Besides, scenario of the material has been constructed with the users' selections in order to offer constructivist and individual learning environment. On the other hand, the developed application supports multiple user opportunity to learn in a cooperative environment. Fundamental features of the material so as to attain the determined learning outcomes have been ordered below:

- Students could interact with the virtual periodic table via physical hand motions and could see 3D atomic models of the selected element,
- Students could review preferences of the chosen element via virtual graphs,
- Students could combine element to acquire a compound,
- Students could see the VSEPR (Valence Shell Electron Pair Repulsion) model and features of the compound,
- Students could access the audial and visual information about the element at the same time with other pupils,
- Students could make practice in that interactive system,
- Offering opportunity for lecturers to create graphics and animations in order to reinforce learning.
- Offering an individualized learning environment with problem scenarios.

Instructional Design

AR as a concept rather than a type of technology that would be more fruitful for educators, researchers, and designers (Wu *et al*., 2013). Based on the most salient features of the approaches, the instructional approaches could be categorized into three major categories: (1) approaches emphasizing engaging learners into "roles," (2) approaches emphasizing learners' interactions with physical "locations," and (3) approaches emphasizing the design of learning "tasks." It is of note that each of the approaches may include several learning principles, and that some sub-approaches may overlap. Also, approaches across different categories may (Wu *et al*., 2013) share a similar philosophical ground or point of view with the educational psychology.

From this point of view, learning needs of the target audience have been determined by the subject expert. The results of the educational need to analyze highlight the several impediments to learn these concepts.

- Students have difficulty to understand intangible concepts.
- Students have difficulty to understand the working principles of micro systems.

- Instead of understanding, students try to memorize the elements and the uncounted relationship between them.
- The supplementary materials to teach these concepts generally use 2D models.
- Students do not have practice opportunities.
- Students do not have the reinforcer to their individual learning.
- Students have several misconceptions about these concepts.
- Students have problems to understand the functions and usage of the elements.

The determined impediments indicate the necessity of experimental learning environment. From this perspective, learning theories and main preferences of the AR platform have been stated in Table 3.

Table 3. The Functions and Learning Theories.

Functions	Learning theories
The theoretic knowledge should be organized by the subject expert. The sub categorizes and relations between the concepts have to be determined	Individual learning Cognitive learning
The material should include the multimedia components –audio, visual, text- in order to satisfy the learning needs of students in accordance with their learning styles	Individual learning Cognitive learning
The visual components should be realistic and high fidelity	Cognitive learning
The students should control the learning environment in accordance with the individual needs- user control, repetition-	Individual learning
Students should control the learning environment via interaction to increase the intrinsic motivation	Individual learning Cognitive learning
Students should make practice freely	Individual learning Constructivist learning
The immediate and constructed feedback should be used	Individual learning Constructivist learning
The material should consists the problem scenarios	Individual learning Constructivist learning
The examples should be offered about the cases	Individual learning Constructivist learning
Students can see the each other’s screens to discuss about the practice	Cooperative learning
Students should compare her practice with the others.	Cooperative learning Individual learning

The main purpose of the determined features is to increase learning outcomes and the problem solving abilities of the students with discovery learning. Correspondingly, several ID components have been integrated in the material. On the other side, the developed material abilities have been given in Table 4.

Table 4. The Used AR Technologies and Purposes.

AR technology employed	Most relevant features	Learning affordances
NUI, HCI ,HMD	Interaction. Navigation.	Experiential learning. Spatial ability. Collaboration. Motivation.

Material plot of the project

As mentioned above, this AR application has been developed in accordance with the individual, constructivist, and cooperative learning theories. Learners can use the material individually with the hardware components. Furthermore, they can control and manipulate each item in the application, and can take constructivist feedbacks of their actions. That structure has been designed to support constructivism. On the other side, the developed software allows multiple user interaction to support cooperative learning. All details about the project has been explained in the related parts of this research. Included functions of the main screens are provided in Table 5.

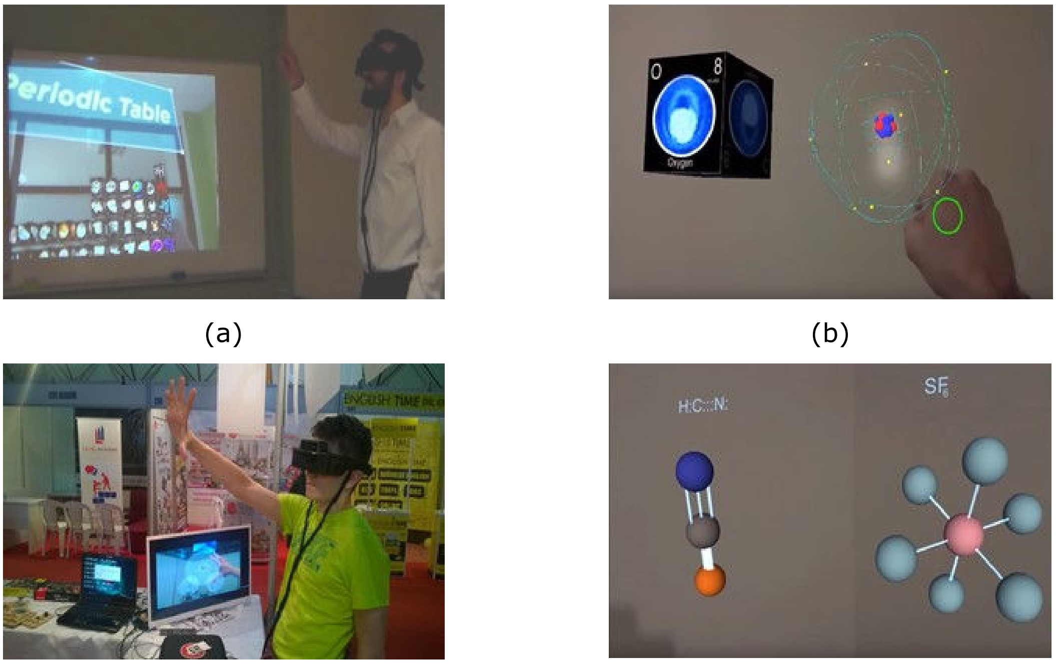
Table 5. The Functions of the Main Screens.

Screen	Functions
Periodic Table	Element selection via hand motion 3D atomic model and graphs
Element review	Visual and audial information 3D atomic model
VSEPR model	Visual and audial information
Element combination	Individual or cooperative practice opportunities Visual and audial information Shared screens to multiple review

The AR application starts with the periodic table screen (Fig. 2a). Then, users can freely choose one of the elements to see 3D atomic model of the element, which consists of graphs and other information about it (Fig. 2b).

Furthermore, students can manipulate the learning environment in accordance with their needs, which means that users are offered with unique and constructed feedbacks. Besides, they can control the objects and iterate the situations in accordance with their learning expectations thanks to the fact that the material offers an individual learning environment.

With this multiple presentation, the intangible structure and sub components of the elements could be imagined as a macro scale. In this regard, VSEPR theory has been rooted in order to handle the learning difficulties of these concepts. According to Singhal et al. (2012), the VSEPR theory can be used to anticipate the shapes of simple molecules by applying a set of simple rules: (1) determine the number of valence electrons of the central atom, (2) identify the number of bonds between the central atom and outer atoms, (3) count the number of lone electron pairs surrounding the central atom, (4) determine overall geometry by the mutual repulsion between the electron pairs, and (5) final adjustments of the geometries such as slightly changing angles due to higher forces of lone electron pairs.



(a) (b)

(c) (d)

Figure 2. Example Scenes, (a) Periodic Table, (b) Atomic Structure, (c) Molecular Structure, (d) VSPER Model.

3D visualization of the atomic models and other details have an enormous significance in understanding the chemical terms and principles. Initial knowledge of the students could be related with the new ones thanks to this method. This approach has been applied to support constructivist learning instead of rote learning. Additionally, students can combine the elements to form the molecule, and they can see the probable results of their decisions (Fig. 2c). Moreover, problem solving abilities of the students can be supported with the constructed and immediate visual feedback opportunity.

Additionally, students can share the visuals thanks to the multiple user support of the software. In this cooperative learning environment, students can discuss their selections and compare themselves with others. By this means, students can learn from each other.

Structure & Flow

As mentioned above, discovery and experimental learning methods have been used to develop this project. Because of the determined learning principles, the scenario of developed AR material does not have a linear structure. This means that the scenario has been branched in accordance with the students' selection. Thus, diagram of the developed AR platform is shown in Figure 3.

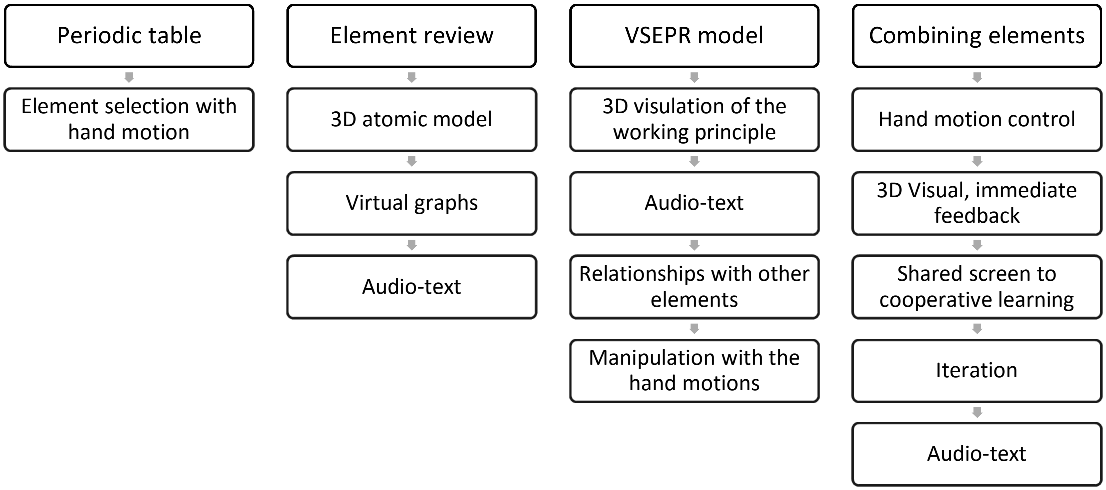
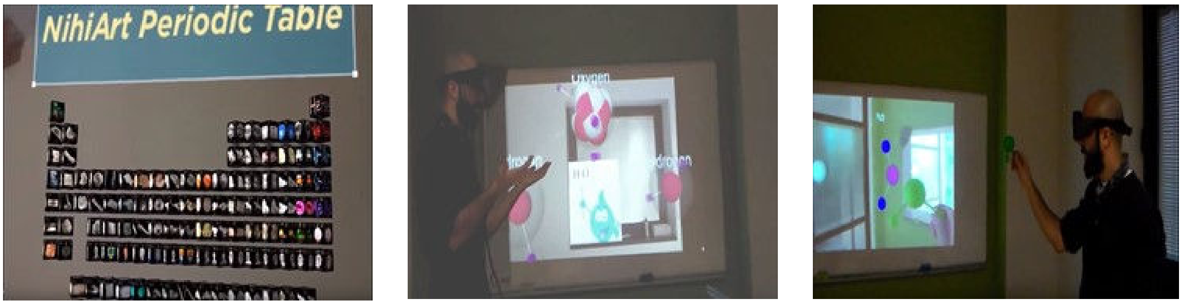


Figure 3. Flow Diagram of the Material.

Also, the screen shots of the developed scenes are shown in Figure 4.



(a) (b) (c)

Figure 4. Developed Educational Scenario, (a) Periodic Table, (b) Molecular Game, (c) VSEPR Application.

The first scenario aims to explain the shape of the periodic table and structure of elements. As seen in Figure 4a, the scene consists of a 3D interactive periodic table. The goal of this scene is to search location of the elements in the periodic table and investigate the atomic structure of the selected elements. The learning task for the second scene is to simulate molecular structure of H_2O and observe the shared electrons. Users need to identify hydrogen and oxygen atoms and place them into the correct area with hand motions in order to create a H_2O molecule. Then, students can observe the structure of H_2O molecule and motion of the electrons. The example of second scene has been provided in Fig. 4b. The third scene has been developed to explore the geometry of individual molecules (VSEPR) and their appearances in nature (Figure 4c).

As seen in Figures 2 and 4, manipulation of the material has been supplied with physical hand motions – touch, grab, drag, drop, rotate. Also, transactions between the screens have been guided with the students' selection. For instance, if the user selects the oxygen from Figure 2a, the 3D atomic model of oxygen would appear as seen in Figure 2b. As understood, the user can review the elements iteratively and observe the 3D models. Moreover, the collaborators can see each other and the shared computer graphics (3D Periodic Table, atomic structures of the elements, *etc*.) synchronously.

Materials & Cost

The developed AR system is based on HMDs, hand and finger tracking software, NUI, HCI, 3D models of periodic tables, atomic structures of elements, VSPER models. The 3D models and animations of the material have been designed and developed with Unity3D and Maya3D.

RESULTS AND DISCUSSION

Current knowledge delivery methods in education should move away from memory-based learning to more motivated and creative education (Singhal *et al*., 2012). As known, the ID has an enormous importance to create effective learning environment that has to be determined in accordance with the students' needs, cognitive abilities and the learning outcomes (Dunleavy & Dede, 2014; Taçgın & Arslan, 2016).

The learning methods and techniques have been increased with the developing technologies and AR is one of the popular and effective learning techniques. As a cognitive tool and pedagogical approach, AR is primarily aligned with situated and constructivist learning theory (Dunleavy & Dede, 2014). Also, AR could enable (1) learning content in 3D perspectives, (2) ubiquitous, collaborative and situated learning, (3) learners' senses of presence, immediacy, and immersion, (4) visualizing the invisible, and (5) bridging formal and informal learning (Wu *et al*., 2013). This project has been developed by using these elements thanks to the fact that, the developed AR application could use both formal and informal education materials. Additionally, the learning content has been prepared by subject expert, and all the information has been organized by the instructional designer to increase the learning outcomes of the learners.

On the other side, the functions of used AR technology offer a roadmap to learning theory selection process. According to the research by Cheng and Tsai (2013), spatial ability, practical skills, and conceptual understanding of students are often afforded by visual-based AR, and location-based AR usually supports inquiry-based scientific activities. As understood, chemistry learners have to be active learners in order to comprehend the intangible concepts. For this reason, the supportive material has to consist of analogies, metaphors and high fidelity visual components to reinforce the learners.

AR examples of chemistry education generally use computer based visualization. However, visualization and high fidelity have extreme significance in order to increase cognitive learning. For instance, Boletsis and McCallum (2013) have been developed a collaborative AR game in order to teach the periodic table and the elements. The computer based project consists 3D clues on a periodic table and multiplayer game scenario. The project offers both collaborative and social learning environment to support learning process. Apotheker and Veldman (2015) mentioned about Molecular City application that consists marker recognition and synchronize 3D monitor visualization and abstract information about the elements. The application also supported by mobile devices and 3D glasses. However, learners cannot manipulate the elements and interact with 3D visuals. That project has been used image based AR technology. Also, there are several image based mobile AR applications such as Atomdroid or NDKmol (Huang, 2015).

In this project, the image-based AR technology has been developed to handle the determined impediments of students in chemistry education. The developed AR system consists of high fidelity 3D visuals and several multimedia components to support conceptual understanding of students. The AR examples of chemistry education has lack of interactivity. The user control of this AR project has been executed with physical hand motions -touch, grab, drag, drop and rotate- in order to observe and investigate the structure of both elements and molecules. In this way, students have been guided to discover relationships between the concepts with iterative practice opportunities. In addition, the AR system allows multiple user interaction with the same virtual chemical structures to support cooperative learning environment. The user control abilities of this project offer interactive, collaborative, individual and active learning environment.

The study of Singhal *et al*. (2012) shows that AR is the enjoyable learning technique to gain more knowledge of molecular structures. Besides, students substantially improve their spatial intuition and learn to better understand visual cues. Similarly, the results of previous studies (Maier and Klinker, 2013; Maier *et al*. 2009) studies indicate that AR applications have an enormous potential to increase intangible concepts in chemistry education. Thus, the perceived fear of chemistry learners has been reserved to the positive attitude. This is absolutely related with the visualization -the spatial relations between molecules and their resulting reaction-. It could be accepted by students because of the new way of controlling and interacting with models of molecules in a playful way (Maier *et al*., 2009).

As understood in the several studies mentioned, the features of the AR should be used to enhance a learning environment. However, ID has an essential process to get reach the determined learning outcomes from the environment. Thus, the educated AR applications have to be designed with an expert team, which should include the instructional designer and subject expert.

CONCLUSION

In this study, HCI based system has been developed to learn the periodic table, structure of the elements, molecules and VSEPR models. The AR technology is used to visualize virtual objects in the RW. The HMDs have been used to set up collaborative learning environment that provides the opportunity to manipulate the virtual objects via hand motions and also, students can learn from each other via shared screens. The fundamental contribution and advantage of the developed system could be explained as any supplementary materials - physical tools (such as mouse, keyboard, marker or glove) – are not required to manipulate virtual objects. Human hand and finger (NUI) motions have been used to manipulate virtual objects instead of the fiducial markers. So, it provides one of the most realistic interaction opportunities with virtual objects.

It is possible to state that interest, anticipation, attention, and wonder of the students could be increased by means of natural hand motion manipulation. Besides, cognitive abilities of the students could be improved thanks to the high fidelity 3D visual designs and other multimedia components. The developed AR application should be applied and evaluated experimentally in order to determine effectiveness of this learning method. Moreover, potential outcomes of similar AR applications should be compared from the ID perspective.

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