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VIRTUAL ENVIRONMENTS FOR CHEMISTRY EDUCATION USING GESTURE-BASED TECHNOLOGY

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VIRTUAL ENVIRONMENTS FOR CHEMISTRY EDUCATION USING GESTURE-BASED TECHNOLOGY

by

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Abstract

Virtual Environments for Chemistry Education Using Gesture-Based Technology

Shaykhah Aldosari

Gesture-based technology has considerably improved in recent years. Such technology allows users to interact naturally with objects in a three-dimensional virtual space. The Leap Motion controller is one example of a device using gesture-based technology, and such devices have vast potential in education. This research focuses on identifying the effects of gesture-based technology on learning, specifically on chemistry education. The research hypothesis is that such technologies in the education field positively influence the general learning experience and improve student comprehension. A chemistry educational system using a gesture-based device and integrating the experiment simulations and the visualisation of molecules in secondary school is proposed and studied. This system provides intuitive methods of conducting chemistry experiments through gesture-based technology and presenting chemistry concepts via macroscopic and microscopic views. The effectiveness of the proposed system is evaluated through a rigorous analysis that includes a mix of quantitative and qualitative research methods. The experimental study results demonstrate that the proposed system improves student learning achievement compared to traditional learning methods. Thus, the proposed educational system results confirm the research hypothesis, indicating the importance of using gesture-based technology in education, as the system can positively influence learning by replacing traditional learning with technology-based learning. Therefore, this research focuses on a new methodology for e-learning, using new advancements in technology. The research also provides a comprehensive understanding of the effect of gesture-based technology, creating a solid foundation for further enhancements to e-learning.

Table of Contents

List of Tables

List of Figures

Chapter 1. INTRODUCTION

INTRODUCTION

1.1 Overview

The growth and development of information and communication technology (ICT) has changed the world. Daily life has changed as technological gadgets have facilitated common activities, such as fitness and communication. The benefits of technological advances are clear, and active research is required to incorporate these concepts into the educational sphere. As technology has brought demonstrable benefits to working environments and other aspects of daily life, universities and schools have realised the importance of researching technology applications to enhance teaching and learning methods. These institutions face a significant challenge in restructuring their educational methods to overcome the gaps and limitations in the current practices through technology and new techniques in teaching, inside and outside the classroom, delivering specialised skills to students in specific subject areas. This technology will result in the delivery of meaningful skills that enhance the professional strengths of the learner and their knowledge (Buabeng-Andoh, 2012; Ghavifekr & Rosdy, 2015; Hennessy et al., 2005).

The human hand is a versatile tool that can be used for many actions: grasping, touching, and more. The hand can perform a range of operations using gesture-based interfaces, such as modifying mechanical equipment, performing surgical procedures and physical rehabilitation (Y. J. Chang et al., 2013; Léger et al., 2018; Rogge et al., 2012). One powerful gesture-based device for human-computer interaction (HCI) is the Leap Motion controller, which was explicitly designed for use with interfaces built for hand-gesture interactions. Its advanced features enable hand-gesture interactions with high accuracy (Ultraleap, 2020b). Over the years, gesture-based technology has advanced tremendously, and these innovations can be adopted in most taught courses to provide a connection between actual and theoretical concepts. Many studies on using gesture-based technology have shown exceptional improvements in learning in major areas (Geng & Disney, 2010; Kellerman et al., 2018; Petrović et al., 2011; Vermun et al., 2013; Vogel et al., 2012; Yükseltürk et al., 2018).

Virtual reality (VR) can be defined as a highly interactive multimedia environment that is computer-generated, in which the user becomes a participant. It creates three-dimensional (3D) simulations of real environments and supports other features and feedback forms, such as sound and tactile effects, which enhance the experience interactions (Çakiroğlu & Gökoğlu, 2019; Rourke, 2020). Virtual technology has advanced substantially over the past decade and is continuously being developed and enhanced (M. M. L. Guerrero, 2014; Padilla et al., 2016; Rayan & Rayan, 2017). Gesture-based technology and VR simulations lead to the development of new technology-based learning methods (Hsu, 2011; Shakroum et al., 2016; Sheu & Chen, 2014). These new learning methods positively enhance education and the learning experience by supplementing traditional learning methods with technology-based learning.

Chemistry is a science that studies matter and its changes, specifically by studying its properties, structure, behaviour, interactions and effects. However, chemistry in education presents difficulties from the perspectives of both teaching and learning. The complexity of understanding abstract chemistry concepts and visualising them at different levels is a significant factor in these difficulties. Teachers find it difficult to explain the concepts, whereas students struggle to comprehend the theoretical and practical aspects. In addition, it is challenging for teachers to offer a practical approach to students and make a course more interesting and adaptable (Millar, 2004; Wan Ahmad & Abdul Rahman, 2014).

Traditional teaching uses such methods as laboratory experiments and visual demonstrations that link student understanding of theoretical rules to physical reality.

INTRODUCTION

However, such traditional teaching methods are ineffective in facilitating student understanding of scientific concepts, such as bonds, forces, molecular structures, chemical reactions and constants, without enabling interaction with their real-world effects (Eticha & Ochonogor, 2015; Gabel, 1999; Gilbert, 2005).

Moreover, simulations and different models evolve the way in which scientific experiments are conducted, with details clear at the molecular level. These mechanisms and models enable teachers to explain and elucidate the scientific principles and processes of the subject to the learners (Smetana & Bell, 2012). Educational software helps teachers provide direct feedback and deliver concepts at the theoretical and visual levels to help students understand complex concepts (Darling-Hammond et al., 2019).

Many chemistry technology-based learning systems have been developed and studied based on different concepts using videos, animations, presentations, evaluation tools and simulations (Nadelson et al., 2015; Savaşci-Açikalin, 2014; Wahab & Thomas, 2015). Although some chemistry learning systems include simulations or object visualisations, they lack virtual manipulation, interaction, and representation of chemistry concepts and how they are interrelated on different levels, such as the macroscopic and microscopic levels (Redel-Macías et al., 2016; Shudayfat et al., 2012). The macroscopic level represents what can be seen in a real chemistry laboratory. It includes chemical properties that can be observed and measured, such as density and solubility. In contrast, the microscopic level represents what cannot be directly seen, such as atoms, molecules and bonds (Gabel et al., 1987; Johnstone, 1993; Petrucci et al., 2010).

Chemistry is an abstract science, making it challenging to comprehend the concepts. Understanding these concepts requires practical applications that may not be feasible in certain circumstances. Moreover, teaching through traditional methods is inadequate, and existing learning systems lack interrelation between the two chemistry views (macroscopic and microscopic), which is crucial for comprehending chemistry concepts. In this research, we overcome limitations in the current learning methods using gesture-based technology and combining the two chemistry perspectives. Hence, we propose a virtual educational system of chemistry that introduces a new method of interaction that can overcome the complications of learning chemistry and increase student learning achievement.

1.2 Research Motivations

Aspects of education are significantly enhanced and supported by educational technologies that increase the effectiveness of the learning process (Ghavifekr & Rosdy, 2015; Noor-Ul-Amin, 2013; Raja & Nagasubramani, 2018). Moreover, technology has facilitated and supported the evolution of educational research with varying research goals and methods (Reeves & Oh, 2017). Technology can be used effectively to support school education and distance education. It also enhances the teaching experience and administrative development (Sanyal, 2001). Technology has the potential to increase the effectiveness of learning in different subject areas and can help students and teachers alike, supporting their roles and increasing their involvement in effective technology-based learning (Noor-Ul-Amin, 2013). The flexibility and availability of education have been greatly improved through technology, developing and enhancing many learning approaches, including critical thinking and problem-solving skills, in addition to various teaching strategies, such as collaborative and active learning. Technology increases student motivation to learn and student-teacher interaction. Generally, technology offers many benefits in the educational process, placing the learner at its centre (Mahini et al., 2012).

Gesture-based technology is gaining popularity in academic and research environments, with systems recently developed for educational purposes in areas ranging from music and special education to art and science (Baratè et al., 2019; Caligiana et al., 2020; Ferreira et al., 2020; Hu & Han, 2019). The gesture-based framework can be used to explore many fields, including chemistry and molecular analysis, and could be a great asset in molecular studies where the forces involved in interactions could be simulated in a virtual system. Molecular structures can be explored in a virtual environment with gesture-based devices to understand better molecular interactions than would be possible with traditional learning (Alsayegh et al., 2013; S.-J. Park et al., 2005; Schönborn et al., 2014). The Leap Motion controller can recognise hand gestures with a high level of accuracy (Bachmann et al., 2014; Vysocký et al., 2020). Such a device can have broad uses in research and e-learning applications. This research adds considerable value and is of interest, as few studies have explored the use of gesture-based technology in chemistry education (Sheu & Chen, 2014). Additionally, most gesture-based educational systems have been developed to represent only the microscopic view for professional chemists and learners (Chinthammit et al., 2015; W. W. T. Lam & Siu, 2017; Rose et al., 2016).

1.3 Research Aim and Objectives

This research aims to examine the utilisation of gesture-based technology, namely the Leap Motion controller, in an educational area, specifically the field of chemistry. The research studies the influence of using the Leap Motion controller as an input device and integrating two concepts, simulation and molecular visualisation, as a chemistry learning method for secondary school students.

INTRODUCTION

This research aim is achieved by conducting an experimental study on a proposed educational system for simulating chemistry experiments and visualising molecules. The system uses 3D graphics for its interface and an easily accessible gesture-based input device, the Leap Motion controller. The system is designed for chemistry education in secondary school and merges two perspectives: the macroscopic view from the perspective of being in a chemistry laboratory and the microscopic view from the molecular perspective.

Combining different perspectives in teaching can help students relate different elements of the learning material and engage their minds. The Leap Motion gesture-based interaction coupled with different perspectives can increase student learning achievement. Likewise, different perspectives impart deeper meaning for students, embedding it further in their minds.

The main objectives of the research can be summarised as follows:

- To study the challenges of teaching chemistry and review the current research on using computer technologies in chemistry education, particularly virtual laboratories and molecular visualisation.
- To conduct a comprehensive literature review related to gesture-based technology and its approaches in this context to explore the advantages and disadvantages of gesture-based interaction devices and their general and educational applications with a focus on the Leap Motion controller.
- To develop an educational system combining simulations of experiments and visualisation of molecules with a 3D graphical user interface (GUI), using a gesture-based device as an interaction device for learning chemistry in secondary schools.
- To identify the effect of the proposed educational system on chemistry learning and assess its usability from the perspective of teachers.

- To test the usability of the educational system and evaluate its interface design and its representation of knowledge and information.
- To identify the effect of the educational system in secondary schools and evaluate the ability of the system to enhance student learning achievements and skills in acquiring knowledge.
- To analyse the findings of this research as they relate to the research hypothesis and evaluate the performance of the proposed educational system and its effect on the educational process to draw the final conclusions.

1.4 Research Hypothesis and Methodology

The primary hypothesis of this research is that the use of gesture-based technology (i.e. the Leap Motion controller) and the integration of simulation and molecular visualisation technologies in education could enhance the teaching process, acquisition of knowledge and improve learning achievement. This research presents an educational system to study the influence of recent technologies, particularly gesture-based technology, on education and discover the effect of integrating simulation and molecular visualisation into teaching. This work uses gestures to interact with the computer and is designed for secondary school chemistry students.

The proposed educational system is developed based on several concepts and methodologies, including gesture-based technology, simulation, virtual laboratories and molecular visualisation techniques. The system uses the gesture-based Leap Motion controller to allow the user to interact with a 3D GUI and simulate chemistry experiments in the laboratory. Additionally, it allows the user to interact with molecular visualisation to explore chemical components.

This study introduces a research experiment to evaluate this educational system. The research experiment includes three research methods: an interview study, usability testing and experimental study, to examine the proposed educational system and its effects on the learning process and assess the research hypothesis. First, the teachers' interview study evaluates the system usability and ability to overcome the limitations and gaps in the existing teaching methods. Then, the usability testing evaluates the system usability and its representation of knowledge. Finally, the experimental study, conducted in a secondary school, assesses the potential to improve students' achievement in chemistry and their understanding of concepts and knowledge. In addition, the study evaluates the ability of the system to improve student understanding of molecular concepts, chemical equations, molecular structures of chemical compounds and chemical bonds.

1.5 Thesis Structure

Following the introductory chapter, background information on computer technologies in chemistry education is provided in Chapter 2, discussing the challenges of teaching chemistry and the use and influence of technology in education. Additionally, chemistry and technology-based education are reviewed. Virtual laboratory and molecular visualisation topics are also discussed, and the research on these topics is presented. Then, Chapter 3 briefly reviews the research concepts, including the history and techniques of HCI, gesture-recognition techniques and components, gesture-based interaction applications and devices, and the Leap Motion controller. Chapter 4 presents the research methodologies and methods. The research methods, strategy, and experimental procedures are covered. Chapter 5 provides an overview of the system development life cycle. Also, it describes the teachers' interview process and findings to identify the user requirements. Further, the educational system concepts are discussed, including the Leap Motion controller and its features, simulation and molecular visualisation. The proposed educational system is detailed in Chapter 5, delineating the requirements, system analysis, design specifications and system description. Chapter 6 presents the interviews with teachers and the usability testing to evaluate the educational effectiveness, usability, user interface and architecture of the system. The procedures and results of these two studies are specified in this chapter. Chapter 7 assesses an experimental study to examine the influences of the educational system and study the ability of the students to acquire knowledge from the system. The methodology, procedures, data analysis and results are described. Chapter 8 details the research hypothesis, main findings, and results regarding the ability of the proposed educational system to enhance learning. Finally, Chapter 9 concludes with a summary of the research and its contributions and a brief outline of future work.

Chapter 2. USING COMPUTER TECHNOLOGIES IN CHEMISTRY EDUCATION

2.1 Introduction

Technology has affected and improved almost every aspect of human life and continues to add ease, efficiency and effectiveness with every passing day. Teaching and learning have also improved with technology, which plays a significant role in the educational field. Learning science subjects has become more accessible, practical, and feasible with the advent of technology and its pervasiveness in the educational system. This chapter first discusses the challenges of teaching chemistry. Then, the chapter reviews the literature on using computer technologies to convey information in education and, specifically, in chemistry education. Finally, this chapter reviews the use of virtual laboratories and molecular visualisation in chemistry education.

2.2 Challenges of Teaching Chemistry

Education is an essential field that is constantly developing and changing (Hubackova & Ruzickova, 2015). Teachers evaluate and re-evaluate their teaching methodologies and adopt new methods to acquire better results. Chemistry is a crucial science known to present challenges to many students who struggle to comprehend it (Sirhan, 2007). It includes abstract concepts and complex theories essential for understanding other chemistry principles and theories (Nicoll, 2001). In addition, learning chemistry requires knowledge of related sciences and skills, such as mathematics and physics (Coll & Treagust, 2003). For many years, researchers have attempted to determine the source of difficulties and factors affecting student understanding of chemistry (de Quadros et al., 2011; Griffiths & Preston, 1992; Johnstone, 1983; Osman & Sukor, 2013; Treagust et al., 2000). Moreover, many studies have identified barriers to student understanding of the concepts and procedures involved in various chemistry topics, including chemical reactions (Boo & Watson, 2001), bonding (Coll & Treagust, 2003; Nicoll, 2001), organic reactions (Eticha & Ochonogor, 2015), chemical equilibrium (Pedrosa & Dias, 2000; van Driel & Gräber, 2003), the orbital concept (Taber, 2002), electrochemistry (Acar & Tarhan, 2008) and atomic structure.

A common factor in many studies is that much of the difficulty experienced in learning chemistry is a consequence of the abstract nature of the matter (Gabel, 1999). Therefore, one of the significant challenges facing chemistry learners is understanding concepts on different levels and how they interrelate (Gabel, 1999). The two basic levels are known as the macroscopic and microscopic levels. Chemistry education presents many challenges, such as understanding the images of molecular representations in textbooks and comprehending molecular structures, chemical bonds and the relationship between atoms and molecules through depictions of molecular representations (Eticha & Ochonogor, 2015; Gilbert, 2005).

The practical application of chemistry concepts in laboratories is one of the most critical teaching methods in enhancing student understanding. However, several barriers restrict this practical application, including the lack of availability of equipped laboratories, the lack of resources and equipment, the difficulty of some experiments, fears for student safety and the safety issues associated with some equipment and chemicals. Chemistry teachers also face a shortage of time to conduct experiments and may have numerous students in a single class (Altun et al., 2009; Tatli & Ayas, 2013).

2.3 Effect of Technology in Education

Teaching and education have evolved over the years through technology use. New technological methods influence both students and teachers. Different methods to exploit technology use in modern education systems have been identified and investigated. All these mechanisms contribute to making technology a critical element of the educational system and creating more interactive and dynamic forms of education (Raja & Nagasubramani, 2018).

The integration of ICT in education helps teachers adopt modern teaching practices and move away from traditional methods. Incorporating technology in classroom environments is crucial to boosting student motivation, involvement and better developing learning skills, including social, problem-solving skills and responsible behaviour. Technology use in schools facilitates a dynamic and innovative environment, increases the knowledge range, improves information-processing capabilities, and develops better attitudes (Ghavifekr & Rosdy, 2015).

According to Noor-Ul-Amin (2013), ICT has improved the methodologies for teaching and how learning practices are executed. Traditional study methods involve content-based education restricted to the classroom and the content the teacher conveys; however, ICT use has prompted modern techniques to evolve, where knowledge is unlimited and easily accessible. This evolution has become possible due to modern technology and communication mechanisms, which have enhanced the quality and accessibility of education and learning.

Many studies have shown the benefits of integrating ICT into teaching and learning. However, the use of ICT in improving education had a negative or no statistically significant effect, according to some studies (Juhaňák et al., 2018, S. Park & Weng, 2020). There are several factors that may prevent students from obtaining the full benefits of ICT based learning methods such as perceived ICT proficiency, perceived ICT autonomy and students' interest in ICT use (S. Park & Weng, 2020). Juhaňák et al. (2018) studied the effect of using ICT in Czech schools and its relation to students' performance. In particular, the results for male students show a positive relationship between students' perceived proficiency and their academic performance in several subjects, including mathematical, science and reading literacy. In contrast, the relationship was slightly negative for female students. Furthermore, there is a strong positive relationship between students' autonomy in ICT use and their achievement in tests.

Xiao et al. (2019) conducted a study to investigate the relationship between several ICT factors and early adolescents' reading ability in five countries with exceptionally high reading ability. They showed that students' interest in ICT and perceived autonomy were closely related to their academic achievement, while for students' perceived ICT competence, the study showed a negative association.

Regardless of these factors, ICT can contribute to the quality and environment of learning and could motivate students and positively affect their academic performance. Various ICT-based tools, including videos, television and computer software programs, can substantially complement the learning process (Noor-Ul-Amin, 2013).

Technology has been integrated into the education system in various ways. The four most prominent integrations include technology as 1) part of the curriculum and learning system, 2) a delivery mechanism for teaching material, 3) a refining method for the learning experience, and 4) a facilitation mechanism for executing the teaching process. Technology is highly effective when the student is the main focus and learning is accomplished at the student’s pace. Technology enables the student to be free in the learning process, directly affecting the teacher’s involvement (Shah, 2013).

The blending of technology in education makes the overall learning process innovative and progressive. Research studies have concluded that technology facilitates the accessibility of information, more robust preservation of acquired information, greater interest from learners in obtaining knowledge, the ease of sharing information and a more interactive learning experience (Chopra et al., 2019; Denan et al., 2020; Shah, 2013).

Moreover, teachers have an essential role to play in integrating technology with education. Teachers who are frequent users of technology can better convey its benefits to the students. Teachers are more confident in using technology and are exposed to new gadgets and methodologies, helping them make lessons easier, appealing, fun-filled, diverse and motivating (M. S. Khan et al., 2012).

Technology has positively influenced the teaching and learning processes, and geographical limitations have been removed with increased globalisation. Alongside the positive points that technology brings to education, challenges are also involved (Raja & Nagasubramani, 2018). Teachers do not always have positive attitudes towards using technology in education (Instefjord & Munthe, 2017; Raja & Nagasubramani, 2018). The most prominent of these challenges is training teachers to handle technology effectively, whether their attitudes are positive or negative (Raja & Nagasubramani, 2018). Semerci and Aydin (2018) investigated the effects of teachers' attitudes towards using technology in education for 353 teachers. This investigation focused on the teachers’ technology experience, skills and training. The results illustrated that their technology experience and training positively affect their attitudes toward technology.

Other barriers to technology use include the lack of time, access, resources, expertise and support. The reliability of the baseline hardware equipment is another significant challenge (Raja & Nagasubramani, 2018). According to M. S. Khan et al. (2012), various internal and external barriers hinder the successful implementation of technology in education. External barriers include deficiencies in equipment, lack of expertise and similar issues, and internal barriers, including teacher concerns and school issues. Conflicts in beliefs and values also pose a significant barrier to accepting the importance of technology and its benefits in education. The lack of expertise, time and skills is the most common problem in integrating technology in the learning process.

Thus, a commitment from governments, administration, teachers, parents and students can enable successfully incorporating technology in education. Software programs must be developed in collaboration with teachers to maximise benefits, and teachers must be trained in using hardware and effective content delivery methods using the latest technological methods and procedures (M. S. Khan et al., 2012).

Considerable research has been conducted to identify the effects of technology use in education and examine its acceptance and the engagement of teachers and students. Using a questionnaire survey, Ghavifekr and Rosdy (2015) explored teachers' perspectives on the effectiveness of integrating ICT in schools. The survey involved 101 teachers from 10 secondary schools in Malaysia. The results indicate that technology can make teachers more confident in learning the procedures and handling equipment. Teachers appreciate that technology and ICT use triggers processes that benefit the educational environment. Effective ICT implementation demands that teachers and students use it progressively; thus, school management has a significant role.

Yildirim and Sensoy (2018) investigated the effects of incorporating technology in teaching science on the achievement of seventh-grade students and the durability of this achievement. The research was conducted in a public school in Turkey for 13 weeks. The results indicated that the achievement of the group taught using the technology was higher than that of the group taught with no technological applications. The study contributed to our understanding of the importance of educational technology in increasing the achievement of students and the need to train teachers to use it.

Isman et al. (2007) investigated teachers' responses to incorporating technology into science teaching. The research examined how frequently technology was used by science teachers in schools in North Cyprus and demonstrated that teachers were cautious about using technology in their laboratories or classrooms. The results revealed no correlation between education level or gender and the approach to using educational technology. However, the responses varied significantly according to the age and experience of the teachers and the school locations. The study demonstrated the need for in-service training to increase teachers' interest in using technology in science teaching.

DeCoito and Richardson (2018) observed how teachers use technology in the classroom and how it can affect science, technology, engineering, and mathematics (STEM) programme development. They found that most teachers were interested in learning about technology, whereas some do not use it because of the unavailability of resources, the time required to use new technology, and doubts about its benefits. The evidence also indicated that teachers were confident with technology, pedagogy, and content. Therefore, increasing the professional development of teachers and focusing on the educational purposes of technology that enhance curriculum development are necessary. These steps will lead to more effective use of technology in education.

Efe (2011) investigated the perspectives of science teachers towards educational technology according to their experience, how they activate technology in the teaching process, and their beliefs in the importance of using educational technology to teach science. The study used a questionnaire survey to collect data from 448 science teachers of different disciplines and school levels in Turkey. The results indicated that teachers who believed in the importance of technology and its benefits in the teaching process had more experience in educational technology. The study concluded that teachers must be trained to use technology in the classroom, which increases their confidence and belief in its importance. Consequently, training increases the opportunities to incorporate technology in education and has an effective role in the teaching process.

2.4 Chemistry and Technology-based Education

Technology is used today in many forms in chemistry education to enhance the learning process. Teachers and learners employ many technology-based learning environments that include presentation tools, such as video, animation and presentation slides, learning tools (Nadelson et al., 2015; Savaşci-Açikalin, 2014), chemistry courses and simulations (Evans & Leinhardt, 2008; Nick et al., 2003). These have been studied through a range of research studies and projects. In addition, online-based monitoring and computer-based assessment tools are further examples of integrating technology into education (Talib et al., 2010; Wahab & Thomas, 2015), as are games and mobile applications in chemistry (G. E. Guerrero et al., 2016; Y. Lin et al., 2015; Tsoi & Dekhane, 2011; Wan Ahmad & Abdul Rahman, 2014).

This section examines various studies demonstrating the effective use of several technologies and their applications in chemistry. Evans and Leinhardt (2008) aimed to explain the greater effectiveness of online chemistry courses over traditional passive and large lecture formats. They selected five online chemistry courses for university students. They analysed these courses using a proposed framework including chemistry and cognitive education research by comparing examples, online features and tasks. They found that each chemistry course provided a different number of examples and tasks with different levels of cognitive complexity. All the courses provided feedback with different types and levels of difficulty, whereas two courses supported only simulation and exploratory procedures. The study results found that technology can promote students' interactions with the course materials, which can help them in developing knowledge frameworks.

A compilation of educational videos to convey key techniques and concepts for laboratory work was developed and tested by Nadelson et al. (2015) to examine the influence of videos in increasing student performance and laboratory knowledge. The study used a sample of 172 students enrolled in an organic chemistry course and found that the laboratory performance and learning of the students improved with high-quality instructional videos in the chemistry laboratory. This study revealed that the technology-based prelaboratory instructions enhanced student performance in the real laboratory and increased their engagement.

Wahab and Thomas (2015) presented an overview of the student experience of an online monitoring and learning tool called MasteringChemistry (Pearson, 2021). This study used a survey of 47 students at the College of Health Sciences at the University of Bahrain in Bahrain to identify their learning content. The results indicated that the students responded positively to MasteringChemistry as an e-learning and monitoring tool, providing academic support through immediate feedback on assignments and quizzes, practice, and revision of concepts. The tool also allows lecturers to explore and monitor concepts, including challenging topics. Moreover, technology improves the learning experience and teaching methods and focuses on the learner instead of the teacher. The tool increases the learner’s independence while enhancing the interaction between students and the educational environment.

Savaşci-Açikalin (2014) investigated how science teachers use instructional technologies in the classroom to increase the student learning experience. Instructional technologies represent the utilisation of hardware and software for the purpose of teaching and learning. Examples of such technologies include PowerPoint presentations, simulations and videos (Savaşci-Açikalin, 2014). This qualitative study aimed to determine the most commonly used technologies adopted by 63 science teachers in the classroom and identify why they prefer these technologies. Most teachers (63%) used PowerPoint presentations in their lesson plans; 30% used video, whereas only 10% used animation. In addition, none of the teachers who participated in this study used computer simulations or educational programs in their lesson plans. These results reflect that they were not familiar with these technologies, which did not meet their needs. The study results demonstrate the need to train teachers to improve their knowledge and technology skills.

Huang et al. (2015) proposed a chemistry online argumentation courseware (COAC) that includes useful website addresses and argumentation activities. Proposing, supporting, opposing, and refining a scientific claim are some of the argumentation activities used in this courseware to conclude valid outcomes (S.-S. Lin & Mintzes, 2010). The COAC allows secondary school students to navigate websites easily and post and discuss scientific arguments to enhance chemistry learning and argumentation skills. The results demonstrated a substantial increase in the willingness of students to argue both individually and in groups as a result of exploring the website support. Moreover, COAC helped students explore the online learning environments easily, regardless of their ability to select useful learning websites. The study concluded with useful principles for educators who intend to improve the use of the e-learning strategy.

Nick et al. (2003) gathered information regarding technology-based learning efficiency using the learning software CHEMnet (IPN and University of Kiel, n.d.). CHEMnet is a web-based chemistry course available for free, with a vast amount of information available to advanced students and lecturers about inorganic and general chemistry. The course is delivered through diverse technology methods, such as video, simulation, animation and an online learning control system. The potential users are university and secondary school students, teachers and lecturers. Most users were satisfied with the content of CHEMnet and considered it easy to understand. The users found CHEMnet easy to navigate and were satisfied with the classification and representation of the content. Many teachers used CHEMnet to prepare lectures and students for their exams. The results indicated the efficiency of technology methods in teaching and learning chemistry.

Talib et al. (2010) aimed to determine the effect of using computer-aided assessment (CAA) learning objects as a self-management instrument to clarify misconceptions and determine the instrument's relationship with achievement and enhanced performance. The CAA prototype consisted of self-assessment questions regarding organic chemistry. The experimental study results indicated that CAA is effective regardless of the feedback given to the students. It helps students improve their performance and identify misconceptions, providing them with the chance to retry. Further, they demonstrated that the technology-based learning approach can be a better alternative to the traditional learning approach. They found that a technology-based learning approach can motivate independent learning and increase academic performance.

Wan Ahmad and Abdul Rahman (2014) proposed a chemistry tutorial for learning based on a mobile game designed to learn challenging chemistry topics. The game covers calculation-based topics, such as chemical equations and formulas. The learners were satisfied with the game and found it to be a useful learning method. In addition, the learners found the challenges and quizzes in the game helpful in learning and increasing their interest in chemistry. The study found that game-based learning applications enhance student interest in chemistry, which increases learning motivation.

A mobile application called Mmacutp was developed to enhance the cation analysis method, which concerns an atom that has lost electrons, becoming positively charged (G. E. Guerrero et al., 2016). The application was introduced in the qualitative analytic chemistry classroom and laboratory to students of industrial chemistry and chemical technology. The results indicated that 94% of the students used the application. Whereas 78% claimed that they could solve the theoretical tasks in the classroom, 87% claimed that their performance was improved through the sample tests. The students also stated that the application helped them in the classroom and laboratory. The study demonstrated that mobile applications are effective in teaching science and provide many interactive benefits. Moreover, chemistry simulations prevent chemical hazards and laboratory risks.

Tolentino et al. (2009) analysed the situated multimedia arts learning laboratory (SMALLab) regarding the productivity of both students and teachers. The SMALLab is a mixed-reality environment created by researchers in arts, computer science, interactive media, psychology and education (Birchfield et al., 2006). SMALLab titration, a learning scenario applying the traditional method of identifying the molarity of a solution of unknown concentration, was developed and implemented in the classroom. The results indicated that the students' knowledge of, and motivation to learn, chemistry was enhanced due to SMALLab. The study concluded that the mixed-reality environment is a helpful learning method for teaching science in schools.

Y. Lin et al. (2015) proposed an educational chemistry game called Valence Bond to understand chemical bonds and molecule shapes. The authors investigated the acceptance of the technology and how learning via games can be useful. In the game, learners must build towers with the correct chemical sequence to fight their enemies. The results indicated that students' knowledge of the molecules and element shapes improved after using the game. Furthermore, the acceptance level of the learners was also high, and the game was easy to operate and suitable for learning. The results imply that educational games help learners understand complex chemistry topics and improve learning effectiveness by practising challenging tasks.

Tsoi and Dekhane (2011) discussed multitouch mobile devices, which can be used to develop applications to teach students the concepts of organic chemistry. TsoiChem was developed using multitouch features, allowing the students to highlight atoms and chemical bonds in the mobile application and use the touchscreen features. The results indicated that instructions to students could be improved using a mobile application and that TsoiChem encouraged mobile learning, allowing students to gain a greater understanding of organic chemistry.

Much research has been conducted to study diverse chemistry learning environments based on various technology concepts. The reviewed literature demonstrates that technology-based learning methods can enhance chemistry learning and overcome the limitations of traditional learning methods. These methods can improve the students' academic achievements and learning skills. They also enhance the interaction between students and the subject and increase their learning motivation. In addition, these results reveal the need to continue researching and developing more effective technology-based learning environments that meet the needs of teachers and students. These needs involve the teaching and learning of chemistry remotely and in schools. Here, we attempt to overcome the gaps in the existing learning methods and increase their efficiency.

2.5 Virtual Laboratory

Virtual reality is a 3D interactive technology that simulates real-world environments and improves the user's interaction experience through different features and reactions. Moreover, VR has been used in many applications and simulations across various disciplines, particularly in education and training (Onyesolu, 2009).

These VR tools allow students to use the laboratory without time limitations and attempt high-risk, complicated, or costly experiments. Moreover, they provide additional features and processes and allow students to apply examination and observation skills correctly. They increase student interaction and motivation and enable disabled students to conduct practical experiments (Onyesolu, 2009).

According to Altun et al. (2009), a virtual laboratory helps students easily understand concepts. It also enhances problem-solving, scientific and creative thinking, data analysis and collection, and observation. Many schools struggle to provide practical laboratory experience due to a range of factors:

- a lack of chemistry laboratories, materials and time;
- crowded classrooms;
- negative attitudes of teachers towards laboratories;
- high equipment costs;
- the inability of teachers to use laboratories;
- concerns due to dangerous chemicals; and
- the need to share laboratories between biology, chemistry and physics courses.

The virtual laboratory has many benefits. It allows students to conduct experiments when they might otherwise be unable to do so and observe events that cannot be naturally observed because the events are too complex, small, fast or comprehensive. Furthermore, data can be collected more easily in the virtual environment, and a large volume of data can be processed rapidly.

According to Potkonjak et al. (2016), a virtual laboratory is a cost-effective method for universities and schools to organise practical work of high quality in science, technology and engineering. One of the advantages of a virtual laboratory is its flexibility: different virtual experiments can be created easily using different components. Furthermore, more than one student can use the same equipment simultaneously, and the parameters can be easily modified. In virtual laboratories, students can cause damage so that they can learn from their mistakes. However, virtual laboratories have the disadvantage of being time-consuming to configure, and the fact that the virtual system does not exist in reality may result in a non-serious attitude on the part of the students. Finally, training is needed, which requires hands-on experience.

Pyatt and Sims (2012) explored how both simulated and physical hands-on experimentation can be used in inquiry-based science to stimulate conceptual access in the first year of secondary school chemistry. The students exhibited positive attitudes regarding virtual and physical experiences and preferred the inquiry-based learning experience (virtual or physical). However, in terms of the usability of equipment and open-mindedness, the study indicated that, in virtual experiences, students were provided with more opportunities to manipulate and explore experimental variables than in physical experiences. Students preferred online and virtual alternatives when accessing laboratory experiences based on inquiry.

Dalgarno et al. (2009) conducted a study on the virtual laboratory for university students of chemistry to examine the effectiveness of the 3D laboratory structure, apparatus and equipment. Although students who used the real laboratory scored higher average scores than students who used the virtual laboratory, the difference between them was not significant. The results indicated that students learn effectively from a virtual laboratory as from a real laboratory. Thus, the virtual chemistry laboratory is an effective educational tool for distance learners who cannot use a real laboratory.

SANLAB (n.d.) is a virtual chemistry software package for secondary schools developed through an educational project in collaboration with several educational institutions in Turkey. Altun et al. (2009) presented and investigated the effectiveness of this software, which allows students to perform various activities at any time or place. Students complete experiments and repeat them with changeable variables, and the results and feedback are presented immediately. The results revealed SANLAB to be beneficial for both students and teachers of chemistry in secondary school when it is not possible to perform the experiments in a real laboratory. These findings demonstrated the effectiveness of the virtual laboratory in teaching chemistry by allowing students to perform and repeat the experiments with different input values.

Students in Nigeria face difficulties in learning science and engineering due to a lack of equipment and materials in the laboratories (Onyesolu, 2009). Moreover, laboratory attendants cannot work all day, every day, and maintenance and procurement costs are also high. Moreover, serious health issues are related to experimenting with radioactive substances. Electric shock and, in the worst-case scenario, electrocution can occur due to problems with faulty material or equipment. Onyesolu (2009) identified that a virtual laboratory could resolve these issues. Students can gain laboratory experience, which motivates students to learn and illustrates the process more accurately. It is a cost-effective method with no risk of electrocution, and students can proceed at their own pace.

Moreover, numerous research studies have presented new virtual laboratory tools and studied their effects on the learning process and on students and teachers. Several of these tools have been explored, and their results are discussed below.

Alexiou et al. (2005) explored the application of VR technology to establish virtual laboratories in education because the setup of scientific laboratories requires significant time and resources; thus, it is infeasible for all educational institutions. However, virtual laboratories are beneficial in educational settings in terms of sharing resources, accessing knowledge and materials, reducing travel, saving time and extending the scope for practical experimentation. The virtual radiopharmacy laboratory supports e-learning using VR technology. At this laboratory, learners use radiopharmacy tools for experiments that support collaborative e-learning. The study found that internet and online courses prompt considerable changes in learning processes and resolve obstacles to using real laboratories, such as time and cost constraints and safety issues. The study concluded that virtual laboratories are cost-effective and upgrade the student learning processes through advanced information technology.

Zaman et al. (2009) explored and examined the development of virtual visualisation laboratories in the particular context of science and mathematics teaching because the existing models and teaching approaches are not very effective. A virtual laboratory, the VLab-Chem, was presented as a tool for chemistry teaching. It emphasises ‘learning by doing’ and contextual learning and fosters active participation in the learning process, directly influencing the students’ self-reliance. The results indicate the effectiveness of VLab-Chem in the context of easy learning, effectiveness and user satisfaction. In addition, VLab-Chem plays a substantial role in stimulating chemistry teaching and helping students retain knowledge over the long term. The study indicated that virtual laboratories improve science learning methods, particularly chemistry.

Redel-Macías et al. (2016) defined the role of the virtual laboratory in biodiesel development. The presented virtual laboratory is a web-based tool allowing students to prepare for a real laboratory, repeat experiments, personalise the process and apply self-evaluation. The authors highlighted the student advantages of using a virtual laboratory, including the ease of use due to 3D animation, motivation and encouragement, and creativity development with boosted self-confidence and learning promotion. Student knowledge and understanding of technical principles can be significantly improved using the virtual laboratory approach with interactive simulations.

The Interactive Chemistry Experiment Platform from Interactive Visualisation Teaching (IVT) presented by Z. Zhang et al. (2017) is an emerging tool of knowledge visualisation that involves visual representation along with HCI. The experimental results reflect that IVT stimulates student learning ability more than traditional methods concerning knowledge of chemistry experiments. In addition, the retest experimental results indicate an advantage of IVT in understanding and memorising chemistry knowledge. However, while the presented tool improves procedural knowledge of chemistry experiments, it does not affect conceptual knowledge. The study results demonstrated that interactive virtual laboratories improve chemistry learning by increasing student understanding and enthusiasm.

Tsovaltzi et al. (2008) proposed a virtual laboratory to support collaborative learning by allowing multiuser and scripted collaborations of scientific experimentation to instruct students. The computer-supported conceptual learning in the virtual laboratory and the collaborative environment facilitate student access to scientific experimentation.

Limniou et al. (2007) aimed to discover an instrumentation teaching method combining traditional teaching and virtual experimentation methods. Ultraviolet-visible spectroscopy is the simulation tool presented for use in virtual experiments. The group that used the simulation tool found this teaching approach more helpful. The approach also allowed them to collaborate and be more confident than the group using the traditional approach. The discussion of the results indicates that instrumentation courses are very frequent in the chemistry curriculum; thus, the theoretical teaching approach employs limited knowledge of the practical application. The simulation application and technical instruments are beneficial in accessing technology in teaching and the visual approach.

Booth et al. (2016) explored the teaching of lactate dehydrogenase enzyme kinetics and laboratory skills to students of biochemistry using the proposed adaptive simulation learning platform. Biochemistry students in the second year at university participated in the experimental study and were randomly assigned to virtual laboratory sessions or conventional classrooms to study the effectiveness of this virtual laboratory. The study sufficiently demonstrated that the new adaptive simulation is useful and can be used in further complex experiments.

These studies confirm the ability of virtual laboratories to enhance chemistry learning, which increases student understanding of macroscopic concepts. Moreover, science education has become safer with technology. Students can perform simulated experiments in virtual laboratories, making them more prepared for real laboratories. There is no risk of errors or accidents when the students perform experiments first in virtual laboratories or on simulation software. They become more aware of the different knowledge and risks involved in conducting chemistry experiments. However, most of the current virtual laboratory and simulation studies have focused only on one knowledge level of chemistry concepts, the macroscopic level. Therefore, this research combines this level with the microscopic level and attempts to introduce the benefits of virtual laboratory and simulation methodologies to achieve the research objective.

2.6 Molecular Visualisation

Modelling molecular chemical structures and simulating their behaviour using 3D visualisation software is an essential part of chemistry. These tools are useful in achieving many purposes, including developing new drugs or materials (S.-J. Park et al., 2006). Molecular graphics are highly restricted, and viewers have little or no ability to edit them (Hanwell et al., 2012). Jmol (n.d.), RasMol (Sayle & Milner-White, 1995) and PyMOL (2021) are examples of available molecular visualisation programs. Many research papers have recently been published in this field, targeted at researchers, scientists, instructors and students. In addition, the effect of molecular visualisation on education has been examined in many studies (Maier & Klinker, 2013; Wongsirichot et al., 2010). Using molecular visualisation as part of teaching has many benefits for students. It helps students visualise abstract structures, making them better comprehend chemistry concepts. Research papers proposing molecular visualisation tools and studying their effectiveness are reviewed below, together with their results.

Wongsirichot et al. (2010) researched a 3D covalent bonding molecular structure stimulating program, a computer-aided instruction program to study basic molecular structures. The program has four primary functions: a perception outlook with explanation, molecule search, list of molecule trees arranged by chemical pattern, and history tab containing the list of viewed molecules. The results indicate that the program helps students obtain a deeper understanding of molecular structure and could be delivered for educational purposes to other universities and colleges.

Moreover, Shudayfat et al. (2012) developed a 3D innovative and collaborative virtual environment for teaching chemistry at the molecular level. For this purpose, a 3D classroom was developed offering different resource types, such as instructional video clips, creatively displayed web links, and learning objects. The results indicated that the group taught using the virtual classroom achieved the lesson objectives to a greater degree than the group tutored through traditional learning methods. Thus, 3D visualisation and the virtual classroom are creative tools for delivering lessons in which students participate actively in the virtual environment.

A cooperative molecular modelling environment was introduced by S.-J. Park et al. (2006), which was implemented using VR techniques. The environment consists of a distributed processing system, a web service, and a VR-based molecular modelling system, which is a system of VR offering users a natural means of interaction. As part of the environmental experiments, docking techniques were performed, and the human immunodeficiency virus was selected as a receptor. The results indicated that VR environments combine interactive manipulation, 3D visualisation, real-time collaboration and reliable simulation in the molecular modelling field. Therefore, this VR environment can be used in different applications.

Comai and Mazza (2010) aimed to develop a virtual environment with a haptic device called Touch to understand the interaction between molecules better (3D Systems, 2021). The 3D environment displayed a geometric molecular structure, within which the user could move the haptic probe to explore the molecule and feel the electrostatic interaction forces between the charge and molecule. The students were satisfied with the tool and understood the concepts, enhancing their interest in the subject. The study results indicated the ability of molecular interaction systems to simulate theoretical molecular models that promote student understanding and increase their interest in chemistry.

Maier and Klinker (2013) proposed a 3D application to understand molecular spatial structures and the atom dynamics between and within molecules. For this purpose, an augmented chemical reaction application was developed with a handle, using a physical cube with a black and white pattern on each side. After several processing stages, a virtual molecule is drawn, creating the illusion that the cube is attached to the molecule and that the physical cube and virtual molecule move together. An experiment with students was conducted, showing a positive response to the application and interest in using it in the classroom. The students understood molecular spatial structures better through the 3D user interface. The study demonstrated a better student comprehension of the spatial structures of chemical molecules using the 3D manipulation application.

Sandvoss et al. (2003) described the design of the Common Molecules collection that provides interactive tools for the 3D visualisation of molecules embedded within the Reciprocal Net (2004) website. The Common Molecules site contains more than 300 collections of molecules, divided into seven groups based on their best-known uses. Students could be encouraged to use the Reciprocal Net Common Molecules site because it enables them to gather information easily about molecules and their structures relevant to their course or applicable in nature. However, the authors did not investigate the effect of the proposed website on the students or teachers.

Talib et al. (2014) studied the use and effect of the computer application Simple Explicit Animation, based on the animation of molecules and electron-moving techniques in an organic chemistry course. The group taught using the electron-moving technique had a better understanding of the mechanism of organic reactions than the group using the traditional, arrow-pushing technique. The study results demonstrated the effectiveness of molecule visualisation in teaching microscopic organic chemistry concepts and increasing student learning achievement.

Moreover, Agarwal and Saha (2011) developed a learning approach based on a game that helps students observe and manipulate relationships between atoms to create molecules. Atom to Molecule game-based application was developed to learn these concepts in a fun way. The number of atoms is constant at every level, but the type of atom is randomly generated. The player is tasked with forming a molecule and solving chemistry puzzles. The game creates interest in studying covalent bonds and is useful in studying the concepts of chemistry.

In addition, Tijou et al. (2006) used the Olfactive Molecules application to describe the effect of olfaction on the understanding, preservation and recall of complicated 3D structures, such as organic molecules. According to different interaction techniques, students could explore stereochemistry, 3D chemical structures, and the constitution of some organic molecules via the olfactory and visual senses with the application. The students could interact with molecules using the immersive and desktop configuration techniques. The results indicated that visual immersion is attained in the immersive configuration with a large rear-projected stereoscopic screen. Motion parallax is provided in both configurations using the camera-based head-tracking technique.

Korakakis et al. (2012) examined three types of visualisation to identify which positively affected the learning process. In the 3D Static Illustrations Interface, the user can only watch the illustrations, whereas the user can also pause and play these illustrations in the 3D Animations Interface. However, in the Interactive 3D Virtual Environment (I3DVE), the user can perform more functions while observing and controlling the illustrations, such as using the mouse and keyboard to rotate and zoom the animations and change the brightness and other features. The results indicated that the highest number of students had correct answers with the I3DVE compared with the other two visualisation types. Therefore, I3DVE is the most effective learning tool of the three and is recommended in teaching science. This result indicated the effectiveness of the 3D interactive molecular environment in understanding concepts of microscopic chemistry.

Korkmaz and Harwood (2004) proposed a 3D tutorial that supports student learning of the abstract concepts of molecules, structures and symmetry elements. A 3D molecular applet was constructed using ADDIE (i.e. analysis, design, development, implementation and evaluation). In the 3D applet, the molecule could be revolved and rotated easily, and pictures and text are also included. The results suggested that the students were pleased with the tutorial and found it usable and beneficial in that it assisted students in the learning process and helped them better comprehend chemistry concepts.

Bakar et al. (2014) researched one of the most difficult topics in mechanical engineering, the properties of matter, in which students have difficulty visualising the arrangement of atoms. A learning software, 3D-Atomic Cube, was developed to teach this subject, using multimedia elements, such as audio, text, animation and 3D simulation. The results indicated that the 3D-Atomic courseware was effective in learning and teaching the subject and helped students achieve better results compared to the traditional approach.

Teaching chemistry can be significantly enhanced by providing virtual representations of molecules. Studies have shown that students experience better learning and concept comprehension using molecular visualisation. However, most studies have been aimed at university students or professional researchers, not school students. Additionally, studies have only been concerned with microscopic chemistry concepts. Therefore, an educational method with molecular visualisation is necessary to exploit the benefits of using macroscopic and microscopic concepts for school students, which is the focus of this research.

2.7 Chapter Summary

Education has benefitted from technology becoming widely accessible, cost-effective and overcoming many of the challenges and obstacles facing learners. Chemistry learners face challenges in understanding concepts and studying matter and its changes at different levels. Virtual laboratories and simulation software can mitigate these difficulties by providing safe and practical chemistry experiments. Moreover, molecular visualisations can help chemistry students understand microscopic concepts and connect them to macroscopic concepts. The usability of technology in education is immense, but the current need is to understand which technologies are more productive, effective and efficient and make them more widely used and accessible on a larger scale. Therefore, the research objective is to integrate different aspects, specifically 3D virtual simulation and molecular visualisation, with the gesture-based interaction method in chemistry education. This integration should make educational technology more effective for learning and supportive for students.

Chapter 3. GESTURE-BASED TECHNOLOGY

3.1 Introduction

The interaction between humans and computers is considered positive, and computers have become omnipresent in today's society (Rautaray & Agrawal, 2015). Embedded in daily human life, computers are essential tools for increasing convenience. Human dependence on computers has made it essential to develop HCI technology. Accordingly, developments in interaction techniques through the direct use of gestures have progressed in the past few years. The gesture is considered a creative and spontaneous technique to interact with computers, and many of the newly released interactive technologies and devices are based on gestures.

This chapter covers the concept of HCI and its history, methods and techniques, as examined in the literature. It surveys gesture-based interfaces, gesture-recognition techniques and gesture-based system components. The chapter also explores the advantages and disadvantages, innovation, and usability of gesture-based interaction devices and their applications. It focuses on the Leap Motion controller because this research aims to examine the use of gesture-based technology in education through an educational system.

3.2 History of Human-Computer Interaction

Hewett et al. (1992, p.5) described HCI as 'a discipline concerned with the design, evaluation, and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them'. Due to the growing need for computer use, it was necessary to develop a 'people-oriented computer' (Nickerson, 1969, p.178). Thus, the need for HCI research emerged in the mid-1970s in response to a demand for the ease of use in computing devices so that all users could effectively employ their functions and features (Myers, 1998). The research started with calls for courses to train people to understand device interactions. In the 1970s and 1980s, many research papers introduced the HCI courses that needed to be taught at the university level. In 1982, the ACM Special Interest Group on Computer-Human Interaction was formed to develop methods and techniques for HCI (Churchill et al., 2013). According to Myers (1998), the history of HCI can be divided into different stages, based on the research on the various techniques used in HCI. For example, research on hardware devices, such as the mouse, began in the 1960s, whereas the mouse entered the commercial market in the 1980s.

Gross (2014) claimed that the emergence and evolution of HCI techniques have been supported by and benefitted from new technology development. The concept of HCI has two aspects: humans and computers. Moreover, HCI was previously considered a collaboration between software technology and the engineering of human factors, with both sides evolving. However, the speed at which the two components evolve can differ. The human side of the reaction is evolving very slowly compared to the technology side. The evolution of HCI was followed by the development of Sketchpad by Ivan Sutherland (1964), which is a computer program that provided interactive graphics in which users were able to grasp objects and move (Gross, 2014).

The next milestone in HCI came in the form of the online system (NLS) computer system (Engelbart & English, 1968), a computer collaboration system offering an interactive text processor, a technique to include tables and figures. At the same time, the computer mouse was invented as part of the NLS in 1965 (Myers, 1998). In 1981, the first personal computer for regular users appeared, the Xerox StarFirst commercial with a GUI, developed at Xerox PARC, followed by the Apple Lisa in 1983 (Myers, 1998). Alan Kay invented the concept of the overlapping windows in 1969, and Kay and Goldberg (1977) introduced the Dynabook notebook.

The next level of development on the human-computer system has undergone several advancements over the last decades. Initially, techniques were developed from the perspective of a single-user system, which included the development of a GUI and various operating systems, pointing devices and menus. Then, the focus moved to developing systems, considering the interactions and collaboration between two or more users at a distance. This focus was followed by research in developing technologies that sense the presence of humans and their requirements and adjust to the user’s requirements (Gross, 2014).

Finally, this evolution has arrived at a point where computer technology can assist the user while also preserving their safety, privacy and security. These various technologies have not replaced one another but are being developed in parallel, as observed in a typical household, where people still use the mouse as the traditional pointing device on operating systems, such as Windows and Mac (Gross, 2014).

3.3 Human-Computer Interaction Techniques

Techniques and devices in HCI have been developed to increase convenience for humans using technologies that assist them in various ways. Some of the key examples include recognising hand gestures, emotional speech, facial expressions and body posture (Jing & Ye-peng, 2013). This section surveys several HCI techniques and approaches described in the current literature.

One of the HCI techniques and approaches is a gesture-recognition approach as an input device for controlling PC applications and computer games. A pointing gesture is used in gesture-recognition systems. The pointing gesture is a robust approach because it requires no preassumptions. However, tracking the pointing fingertip and estimating direction are complex tasks (Jing & Ye-peng, 2013). Jing and Ye-peng (2013) proposed a real-time approach for the pointing gesture-recognition scheme using an adaptive touchscreen and a Kinect, a motion sensing device for the Xbox 360 gaming console (Microsoft, 2021). The experimental results revealed the system robustness and demonstrated that the proposed system could accept input from small or large gestures.

Palacios et al. (2013) presented a novel approach for gesture-recognition systems that used Red Green Blue-Depth (RGB-D) sensors. Depth information, such as background and occlusion, is considered by the proposed system, and colour and semantic information are also used in the recognition process. In this work, 10 static and six dynamic hand gestures were used in the evaluation process. The experimental results demonstrate the system robustness in hand movement freedom in which it can detect hand motion in any direction and at a high distance range.

A markerless hand-tracking system that is fast and robust and uses low-cost hardware for flexible HCI to control games was presented by Yeo et al. (2015). The system supports two input devices, the webcam and depth camera. These input devices are utilised for recognising gestures and can be used to control computer applications and video games. The design resolved many previously identified difficulties, such as backgrounds that do not contain skin-coloured objects and the need for a long-sleeved shirt. Haria et al. (2017) proposed another hand-gesture detection system that does not require markers and can handle dynamic and static hand gestures. The system input is hand gestures that are transformed into specific actions, such as browsing a website or running or starting software applications.

Rautaray and Agrawal (2012) presented another technique to help humans interact with computers, using visual perception to identify hand gestures. The identification of gestures involves observing the motions to convert and represent the input in the form of a meaningful command. The research aimed to develop a system capable of identifying human gestures and a process of controlling user interfaces in dynamic environments. The proposed design can control different applications, such as image browsing and games via hand gestures.

Moreover, emotional speech recognition is another HCI approach. A hierarchical structure for emotion-recognition systems, a prime aspect of HCI, was proposed by C.-C. Lee et al. (2011). In this work, acoustic speech features are considered, and a binary classifier is used to categorise emotions into one of five classes. The results demonstrated a 3.3% improvement in accuracy over the baseline technique.

Facial expression recognition is also an HCI approach. Jampour et al. (2017) introduced a multiview facial expression recognition system for various head poses. The proposed approach was tested with different experiments, using several datasets, and the experimental results exhibited higher recognition accuracy than existing techniques. In addition, H. Zhang et al. (2018) presented an ergonomic pose-detection system using 3D view-invariant features projected from a 2D camera. This proposed system aimed to recognise and evaluate painful and risky postures for construction workers. It included views of the arms, back and legs. The system exhibited an accuracy rate of 98.6% for the arms, 99.5% for the back and 99.8% for the legs, increasing the safety of construction workers.

One HCI approach is the body-posture recognition approach. The body-posture recognition system involves feature extraction and classification processes, which require more processing time. Okuno et al. (2018) presented a body-posture recognition system to monitor the driver’s position and control the self-driving system. The body posture and facial orientation of vehicle drivers are estimated simultaneously in the system. The results found accuracy rates of 98% and 91%, respectively, for these two estimation tasks.

Furthermore, gaze/eye tracking is an HCI approach. Arai and Yajima (2011) presented one such technology that used computation to control a robotic arm to create a meal support system controlled by input from the human eyes. Using a computing system to move the robotic arm has been proved to increase the speed of the operation by 21% compared to the manually moved robotic arm. Therefore, the technique contributes to more effective interaction between the computer and people with disabilities.

According to previous research studies, the diversity of current HCI technologies and methods, such as hand gestures, facial expressions and body posture, can be deduced with significant improvements in accuracy and efficiency. In addition, the growth of using HCI techniques and approaches in many fields and applications, such as training, rehabilitation, and entertainment, can be deduced. The vast popularity of HCI applications leads to continuous progress in the development of HCI devices, which has made it an increasingly interesting research field. Therefore, the development of technologies encouraged studying one of the HCI approaches in this research, which is hand-gesture interaction. It also inspired studying its effects in an important and vital field, which is education.

3.4 Gesture-based Interfaces

Human-computer interaction technology has changed the use of computing devices. Gesture-based interfaces and methods can be considered a natural and intuitive HCI approach. In the early days, a pen-based, gesture-recognition system was developed (Oviatt, 1996) for write-up purposes on mobile and personal digital assistant devices. Glove-based gesture techniques were introduced for HCI (J. Y. Lee et al., 2010; Yoon et al., 2012). These glove-based gesture interfaces were used for interaction with VR applications to allow users to work with objects using hand motions and other body motions. In the 1980s, the first vision-based gesture interface was introduced (Premaratne, 2014). Vision-based gesture methods attracted the interest of researchers in the HCI domain. These techniques are still up to date in the research community (Jiang et al., 2016; Laskar et al., 2015).

According to Rautaray and Agrawal (2015), two primary categories of technology are used in developing gesture-based systems with a high level of effectiveness: vision- and contact-based techniques. The contact-based technique requires physical contact between the user and the tool used as an interface, and such devices can be used only by experienced users and not by novices and, therefore, offer restricted accessibility. Such devices are developed using technologies including the accelerometer, data glove and multitouch screen. In contrast, vision-based devices are used to identify human hand gestures and take them as input. These devices capture video sequences using one or more cameras. Various challenges are associated with vision-based devices, including coping with a continuous variation in hand gestures, making it difficult for the device to detect gestures and convert them into a particular command correctly. Examples of contact and vision-based devices are illustrated in Figure 3-1.

(a) (b)

Figure 3-1 (a) CyberGlove III (Henderson et al., 2021) and (b) SoftKinetic HD camera (Dihl et al., 2021).

The literature includes many studies related to various aspects of gesture techniques. For example, some studies have treated gestures as movements of the arm and hand (Jadooki et al., 2017; Rosa-Pujazón et al., 2016), whereas others considered gestures a movement of the head (Zhao & Allison, 2019). Moreover, many studies have considered facial expressions to be a gesture interface (Lyons, 2004). The various scientific papers and general concepts of gesture-based interfaces and their different techniques and applications are highlighted and studied in the following sections.

3.4.1 Gesture-recognition techniques

Gesture-recognition techniques are classified into three categories based on the type of input device: glove-based gesture recognition, accelerometer-based gesture recognition and vision-based gesture recognition (J. Cheng et al., 2013). These techniques are reviewed below.

a. Glove-based gesture recognition

Individuals typically use their hands for a wide range of control and correspondence tasks. Besides being very helpful, the human hand is adroit and expressive and has 29 degrees of freedom (DoF) with the wrist (Turk, 2015).

Sturman (1992) showed that the human hand could be used in many applications as an advanced control and input device, giving continuous control in complicated functions with several DoF. Sturman proposed a scientific classification of a whole set of hand inputs, ordering input procedures based on two measurements: hand actions that can be discrete or continuous and those that can be direct, mapped or representative.

Glove-based commercial tools have become accessible, which helps measure the varying degrees of completeness, precision, and accuracy and the configuration and position of the hand. Exoskeleton and data glove devices fixed on the fingers and hand of the user are widely used. Instrumented gloves offer several benefits, including the direct computation of hand parameters, including joint angles, 3D spatial information and wrist rotation. Instrumented gloves also provide data at high frequency, remove problems related to line-of-sight occultation, and are easy to use (Turk, 2015).

Various glove products have been designed and developed in the scientific literature for gesture-recognition systems. A. Ali et al. (2016) used a glove built using 11 sensors installed at different positions and implemented four different machine-learning algorithms to identify American Sign Language (ASL) and translate it into text. The results of the proposed system were up to 99.3% accurate using a neural network algorithm.

Cavallo (2011) proposed a new approach using a data glove with 18 markers (three markers for each finger and three for the base reference system) and five infrared cameras. The study demonstrated the effectiveness of the proposed experiment using a data glove with markers to recognise complex actions. Moreover, Camastra and De Felice (2013) used a DG5 VHand 2.01 data glove for feature extraction through a hand-gesture recognition system. The DG5 VHand 2.0 recognises hand movements and orientation with five bend sensors registered for DGTech Engineering Solutions (2013). The updating time was 20 ms per finger for this wearable glove, and its recognition rate was 99%, demonstrating the efficiency of the proposed recognition system (Camastra & De Felice, 2013). These studies indicated the effectiveness of glove-based gesture recognition, which explains the development of the data glove commercial production and applications.

b. Vision-based gesture recognition

The vision-based interfaces use one or more cameras to capture images at a minimum frame rate of 30 Hz. These images are processed to enhance visual characteristics that can recognise gestures and interpret various human activities. Generally, camera locations are fixed, although they can also be fixed on both moving and nonmoving platforms (Turk, 2015).

Two distinct methods of vision-based gesture recognition are image-based and model-based methods. Model-based methods build a 3D model representing the hand of a user, which is used for recognition. In contrast, image-based techniques are focused on measuring the gestures of recognition directly from the hand image (Billinghurst & Buxton, 2018).

Zabulis et al. (2009) examined vision-based gesture recognition, studying three fundamental difficulties in this approach – detection, tracking and recognition – and reviewing related studies covering several vision-based gesture-recognition systems. Moreover, they proposed a gesture identification system to provide and manage the interaction between humans and robots to guide people when visiting exhibitions and museums. The results demonstrated the efficiency and effectiveness of the system by achieving better accuracy and runtime performance. The study concluded that vision-based gesture recognition is a more natural means to interact with computers and applications that focus on the user's perspective. These results explain the increased interest in research related to vision-based gesture recognition (Zabulis et al., 2009).

c. Accelerometer-based gesture-recognition interface

One considerable technology in gesture recognition is the accelerometer, which adequately meets the needs of a wide range of computing environments. With the increased growth in micro-electromechanical systems (MEMSs), users may carry or wear more than one accelerometer-equipped tool in their everyday lives, such as the Nintendo Wii Remote or Apple iPhone (A. H. Ali et al., 2014). These wearable and mobile wireless-enabled tools create new possibilities for communicating with many applications, such as mixed-reality and home appliances (J. Wu et al., 2009).

This technology has gained rapid acceptance in a short time. The accelerometer’s small size and low-to-moderate costs are important determinants, making it an appropriate tool to recognise and detect human gestures (Aggarwal et al., 2013). In an accelerometer-based system, the initial step is to obtain the time series for gesture motion (J. Wu et al., 2009).

Moreover, an input device based on finger gestures has been developed with an acceleration sensor, bend sensor, touch sensor and infrared transmitter. O’Flynn et al. (2013) developed a smart Tyndall/University of Ulster glove containing 16 tri-axial accelerometers, 20 bend sensors and 11 force sensors. The authors studied the sensor glove in rehabilitation to obtain advanced sensor stability and flexibility (O’Flynn et al., 2013). Na et al. (2021) developed an accelerometer-based system for recognising Korean sign language. The system uses a motion sensing module that is fitted on the proximal phalanx of the index finger and its data is transferred via Bluetooth. The system showed high accuracy in recognising the 31 Korean language letters ranging from 87.1% to 98.6%. Thus, accelerometer-based gesture recognition can have applications in different fields and provide reliable recognition of hand gestures.

Bakshi et al. (2020) investigated the use of an accelerometer and gyroscope module to control robotic arms, which is useful in fields such as medical, hazardous conditions and industries. The gyroscope module is a sensor that can measure the angular rotational velocity of an object, while the accelerometer can measure the linear velocity. The authors designed a system to replicate the user’s hand movement along with the fingers to move a robotic arm with 5 degrees of freedom. A glove-based device with a mounted 3-axis accelerometer is used to control the robotic arm. The results showed that the system was user friendly and easy to control and provides precise movements of the robotic arm, which is useful in fields such as medical, hazardous conditions and industries. Therefore, accelerometer gestures recognition has advanced over the years, which made it useful in imitating actual hand movements.

A sensor box is placed inside the user’s smartphone to capture the three-axis acceleration of a user's hand motion. More motion data can be conveyed using 3D accelerometers than when using 2D accelerometers (J. Wu et al., 2009). Such accelerometers have been placed into many commercial products, including the Wii Remote and iPhone (A. H. Ali et al., 2014).

Akl and Valaee (2010) presented a hand-gesture recognition system using a single three-axis accelerometer built in the Wii Remote. The results of the proposed system for user-dependent recognition were 99.79% using an 18-gesture dictionary and, for user-independent recognition, 96.89% using an eight-gesture dictionary. The study indicated that accelerometer-based gesture recognition provides a natural HCI with high accuracy. Therefore, it is frequently embedded into many personal devices (Akl & Valaee, 2010).

An accelerometer-based system for ankle rehabilitation was developed by Covaciu et al. (2020). The system was designed to rehabilitate patients using simulations of an intelligent robotic system. The accelerometer-based sensor is attached to a patient’s limb and can be used to identify the muscle tone, position and acceleration of the lower limb. Their system uses machine learning, and it achieves a high accuracy of 81.35%. Thus, accelerometer-based devices have huge potential due to their small footprint and high recognition accuracy, including fields such as medical rehabilitation.

3.4.2 Gesture-recognition system components

In some literature, a gesture-recognition system comprises three components: gesture modelling, gesture analysis, and gesture classification (Pavlovic et al., 1997; Sultana & Rajapuspha, 2012). A diagram of gesture-recognition system components is displayed in Figure 3-2.

Figure 3-2 Diagram of gesture-recognition system components.

Gesture modelling considers the models used to present hand gestures. Effective hand-gesture modelling should relate directly to the HCI gestural interface. Gesture modelling encompasses different modelling types, such as the temporal and spatial modelling of gestures. In addition, temporal modelling comprises three phases: preparation, nucleus and retraction. In the preparation phase, the hands are set in motion from a resting situation. In the nucleus phase, the hands are provided with a definite form that represents enhanced dynamic qualities and, in the phase of retraction, to enter a new gesture phase, the hands return to the resting position (Pavlovic et al., 1997).

In another type of modelling, the spatial modelling of gestures, a 3D hand model is used to estimate arm and hand parameters. This type of modelling uses appearance-based models, in which the visual image is associated with the appearance of the hand and the arm to create certain gestures. Figure 3-3 outlines the classification of spatial models of gesture representation.

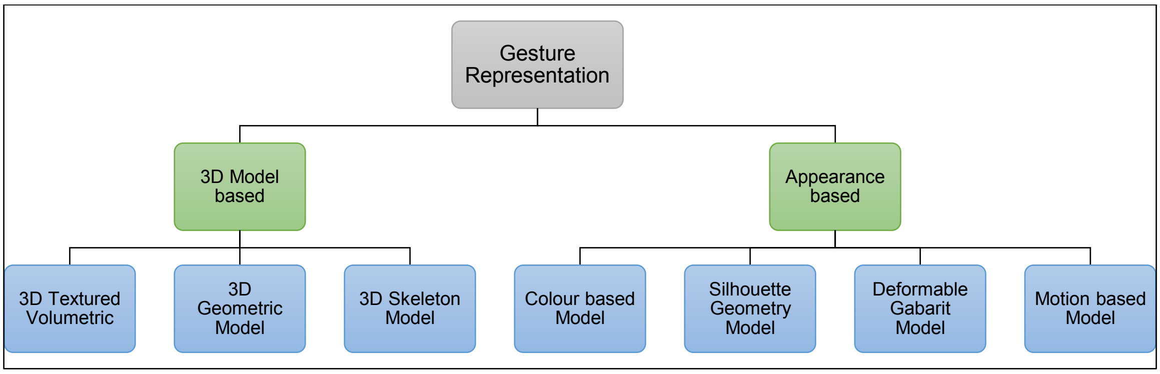


Figure 3-3 Classification of spatial models of gesture representation.

The 3D models constitute the prime choice in gesture modelling. They obtain hand gestures through video input, followed by image processing. In this model, various parameters are calculated to obtain a 2D image, and the two images are compared to assess their similarity (H. Cheng et al., 2016; Y. Wu & Huang, 2001). The primary function of these models is the identification of matching body postures with the synthesised 3D body model (Pavlovic et al., 1997). The 3D models are categorised into volumetric, geometric and skeletal models (Rautaray & Agrawal, 2015). In appearance-based models, the object parameters for the performed gestures are not immediately derived from the spatial representation but are outlined through the video input of the hand gesture, followed by a comparison of the 2D image with the predefined model template database (Pavlovic et al., 1997).

Gesture analysis is the second stage of the system and includes two major components: feature detection and parameter estimation (Kang et al., 2014). The feature detection process is started by determining the person’s position when making the gestures and then extracting the required features. Zabulis et al. (2009) discussed some of the detection methods. In the localisation process, the object is detected from the image and segmented from the background. Cote et al. (2006) studied several segmentation approaches and discussed their performance before presenting a novel segmentation approach, integrating two different approaches for improved performance.

The localisation process can use colour and motion cues. Colour cues rely on the colour footprints of the human skin. These colour footprints must not be sensitive to illuminative changes and should be distinctive with such changes (Pavlovic et al., 1997). Skin colour is considered an effective and efficient approach for hand localisation (Y. Wu & Huang, 2001). However, Kakumanu et al. (2007) noted that this technique has certain drawbacks: human skin colour changes according to the lighting environment, and the skin colour varies when using different cameras. Motion cues are also used for feature detection, with specific assumptions about the gesture and background, as demonstrated by Bayazit et al. (2009) and Castellano et al. (2007). The feature fusion method that combines two cues, such as skin colour and motion cues, is used to overcome the problems of applying these cues individually (Brethes et al., 2005; Cui et al., 2012; Ma et al., 2009). After localisation and feature detection, the next phase of the gesture analysis process consists of computing the parameters. Different image features are used to estimate the parameters: geometrical features, such as contours and fingertips, and nongeometric features, such as the silhouette and colours (Y. Wu & Huang, 1999).

The final stage in the gesture-recognition system is gesture classification. In this stage, gestures are recognised from the data analysed from different visual images. In this phase, the partitioning of the parameter space is conducted optimally, and the recognition procedure is implemented considering the computational efficiency. It has become evident that the time-space context of the gesture should be considered vital for a successful recognition scheme (Pavlovic et al., 1997).

3.4.3 Gesture-based interaction devices and applications

The scope of gesture-based applications has vastly increased in recent years, and many different examples of devices and applications have been used to implement gesture interfaces. Initial developments based on gesture control have been focused on computer applications, such as text editing and browsing. However, due to advances in technology, gesture-based applications are now used in various areas, including entertainment, home activity, health care and care for people with disabilities, replacing traditional input devices, such as the keyboard and mouse.

Microsoft Kinect (Microsoft, 2021) can be employed for hands-free motion-control gaming. It can sense full-body motions and comes with a vast repository of gestures. It was developed for Microsoft’s video gaming console, Xbox 360, to track, capture and interpret human movement and gestures to play the game and enhance the entertainment experience of the players. It also supported the interpretation of human voices. Thus, players can play the game as if they are immersed in its environment, not restricted by a specific joystick, mouse or keyboard-based controls and inputs (Berger et al., 2013; Hsu, 2011). Additionally, the release of the Microsoft noncommercial Kinect software development kit (SDK) in 2011 made the use of Kinect convenient and possible in such fields as education and physical rehabilitation (Berger et al., 2013; Y. J. Chang et al., 2011; Pavone et al., 2019; Vermun et al., 2013; Wattanasoontorn et al., 2013).

The PrimeSense family is another range of sensors based on structured light, which observes the scene in 3D and determines the depth and colour of the image stream (Zollhöfer, 2019). PrimeSense is applied in gaming applications and other automation and robotic applications and consists of two sensors: the Carmine and Capri sensors (Calderita et al., 2012). The Capri sensor has great potential. It is small and low cost and targets the mobile market (Crabb, 2012). The PrimeSense Carmine 1.09 is illustrated in Figure 3-4 and is employed in many applications and studies (Anxionnat et al., 2018; Iversen & Kraft, 2018; Rajagopal & Siddiqi, 2015).

Asus Xtion is a 3D sensing device based on PrimeSense structured light to observe a scene in 3D and comes in three versions, Xtion, Xtion Pro Live and Xtion 2. Xtion provides depth data only, whereas Xtion 2 provides RGB and depth data, and Xtion Pro Live determines depth data, RGB images, and sound signals, similar to the Kinect but less popular. However, Xtion supports different operating systems – Windows, Linux, and Android – whereas the Kinect supports only Windows and does not require a power supply because it uses a USB connection. The Asus Xtion Pro Live is illustrated in Figure 3-5 and is widely used in entertainment and gaming applications and diverse research areas (Aagela et al., 2017; Chavez & Karstoft, 2014; Guan & Meng, 2012; Nock et al., 2013).

Figure 3-4 PrimeSense Carmine 1.09 (Li et al., 2015).

Figure 3-5 (Left) Asus Xtion Pro Live and (right) Microsoft Kinect v2 (Rehouma et al., 2020).

The Leap Motion sensor is another gesture-based sensor that has employed visual techniques to change the way humans interact with a computer. The small device can detect finger movements with great precision when connected to the computer and observe the scene in 3D (Hodson, 2013; Marin et al., 2016). The device provides greater accuracy than the Kinect sensor, considering the sampling rate, depth resolution and frames per second (fps; Guzsvinecz et al., 2019). Moreover, the Leap Motion sensor offers users very precise and domain-specific interaction; therefore, it is considered a potential device in gesture recognition applications (Hodson, 2013; Marin et al., 2016). The Leap Motion controller is described in detail in the next section.

Many research studies have discussed the latest gesture-based interaction devices and compared and highlighted their features, advantages and limitations. The following section reviews some of these studies.

Diaz et al. (2015) presented a comparative quantitative analysis of the Kinect v2 and the Asus Xtion Pro, which uses first-generation RGB-D sensors, in reference to two specific application scenarios: object recognition and 3D construction. Diaz et al. (2015) compared the technical features of both the Asus Xtion Pro and Kinect v2. The assessment of accuracy was validated through a meteorological laser scanner. The Kinect v2 had better results, with a high rate of object recognition and high accuracy of pose estimation, which is the process of tracking and predicting the position and orientation of an object. In addition, the study determined that Kinect v2 renders better results in real-time environments and, despite slight issues, Kinect v2 can also cope and render better results in computer vision applications.

Kuan et al. (2019) compared the performance of three sensors, Kinect v2, Intel RealSense R200 and Asus Xtion Pro Live. These three sensors were compared in indoor and outdoor scenarios with the interference of natural sunlight, with special reference to capturing the 3D surfaces of objects. The Kinect v2 exhibited the best results in short-range use of the 3D sensor in metric measurement and capturing 3D surfaces of objects in both outdoor and indoor setups.

Gonzalez-Jorge et al. (2013) conducted a comparative study of the Kinect and Xtion sensors. All sensors had similar results concerning precision and accuracy for all angles under study. Moreover, the results demonstrated that the sensors, including Xtion and Kinect, have potential in a wide range of engineering situations, with particular relevance to low-range applications in an indoor environment with medium accuracy requirements.

Zou et al. (2016) aimed to determine the differences between and the benefits of certain RGB-D sensors: Kinect v2, RealSense R200 and Xtion Pro Live. This study compared three sensors, demonstrating that Kinect v2 performs the best but is heavy and cumbersome. However, the RealSense R200 is also suitable for unmanned aerial vehicles and small robots and, unlike Kinect v2, does not need an additional power supply.

Guzsvinecz et al. (2019) proposed the Kinect sensor and Leap Motion controller concerning their potential as substitutes for more expensive sensors in the market. They presented various comparative tables relating to different criteria associated with whole-body tracking devices to highlight the features of the two devices over others. Previous studies on the Kinect, Leap Motion controller and their collaborative usages were defined and reviewed to compare the two Kinect sensors v1 and v2 and the Kinect v2 and Leap Motion controller. The article concluded that these two devices are comparatively better than their more expensive competitors, such as Xtion Pro Live and Intel RealSense D415 (Guzsvinecz et al., 2019). Additionally, they are suitable for use in various applications, including education, entertainment and rehabilitation. One of the most accurate low-cost devices for tracking hand movement in the market is the Leap Motion controller, while for whole-body tracking is the Kinect (Guzsvinecz et al., 2019). Guzsvinecz et al. (2019) compared the sample rating and the cost of the Leap Motion controller with other tracking devices such as Myo Armband and Creative SENZ3. The study found that the Leap Motion controller is more accurate than the two Kinect sensors v1 and v2 (Guzsvinecz et al., 2019; see Table 3-1).

Device	Sample rate	Frame rate	Field of view
Leap Motion controller	50–200 Hz	200 fps	140x120°
Kinect v2	30 Hz	30 fps	70x60°
Kinect v1	30 Hz	30 fps	57x43°

Table 3-1 Comparing the sample rate, the frame rate and the field of view of the Leap Motion controller, the Kinect v1 and the Kinect v2 (Guzsvinecz et al., 2019).

Vokorokos et al. (2016) conducted a detailed assessment of gesture-recognition platforms. The efficiency of gesticulation was examined across three key platforms: Leap Motion controller, Microsoft Windows Kinect and Myo Armband. The study presented a comparison of these three platforms to evaluate their effectiveness for recognising four different gestures: rotation, fist, pointing and waving, based on 50 measurements (Vokorokos et al., 2016). The results of the Leap Motion controller are the best of the three in pointing, hand rotation and fist recognition. However, the study suggests that each device has satisfactory results in different areas. The Leap Motion controller is satisfactory when controlling in front of the computer, and the Kinect and Armband are satisfactory when controlling from a distance.

Carvalho et al. (2018) compared two gesture devices, the Leap Motion controller and Microsoft Kinect, with the help of Fitts' law model to examine target acquisition performance across three user groups: young adults, older adults and children. The data were gathered from 60 participants, who were asked to select tasks continuously at a quick and accurate pace using any single gesture device. The analysis of the results demonstrated statistically significant differences between age groups; however, on examining user performance according to input devices, no significant differences were found in any user group. Therefore, the user performance may not be influenced by the device but by age.

Pittarello et al. (2018) focused on the interactive 3D environment and various input devices to provide the desired experience for players, specifically a gamepad, mouse and keyboard, and Leap Motion controller. These input devices were compared for their control in the 3D-based educational gaming environment, focusing on environmental sustainability. The comparative study was performed with 30 children, and the effectiveness of interaction was assessed in terms of engagement, usability and physical fatigue. The findings are favourable for the Leap Motion controller and its gesture-based interaction due to its high compatibility with gaming platforms and desktop environments. However, compared to similar devices and interactions, it may be less familiar. Children benefit from gesture-based interactions because they tend to simulate real-world actions.

3.4.4 Leap Motion controller

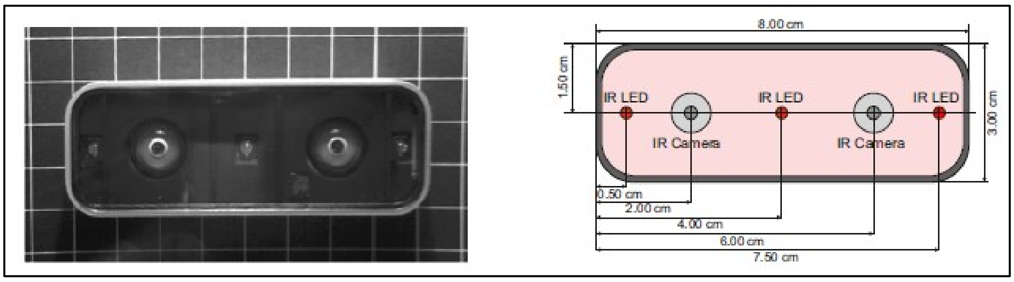
In recent years, considerable attention has been focused on touchless interaction to eliminate the burden of physical contact. The recent emergence of unique devices, such as the Leap Motion controller, has enabled the acquisition of informative data about hand motion and pose that can be employed to recognise gestures with a high degree of accuracy. David Holz and Michael Buckwald founded the Leap Motion company in 2010. The company announced its first product, ‘The Leap’, on 21 May 2012, started shipment by 2013 and released a second version of the software in May 2014. They sold the product to UltraHaptics in 2019, and its name changed to Ultraleap (Leitão, 2015; Ultraleap, 2020b).

The Leap Motion controller is a sensor device designed and developed to identify hand gestures and finger positions for HCI (Ultraleap, 2020b). The device is equipped with infrared cameras and sensors that can recognise hand and finger movements and identify specific hand gestures (Bachmann et al., 2014; Chan et al., 2015; Vysocký et al., 2020).

3.4.4.1 Hardware and software of the Leap Motion control

The Leap Motion controller is a small device with dimensions of 80 x 30 x 11.3 mm and weighs 32 g (see Figure 3-6; Ultraleap, 2020a; Vysocký et al., 2020). The controller comes in a brushed aluminium body with mounted glass on its top surface. It consists of three infrared light-emitting diodes (LEDs) and two charge-coupled device cameras that can track light with a wavelength of 850 nm to compute the depth and distance of a hand. The controller is equipped with infrared LEDs that beam infrared light in no particular pattern. A schematic view can be observed in Figure 3-7, displaying the Leap Motion controller components. The sensing area of the device is an inverted pyramid around 0.2 cubic metres in volume. The device has a field of view of 140×120° with a limited interaction range of approximately 10 cm to 60 cm, as depicted in Figure 3-8 (Bachmann et al., 2018; Ultraleap, 2020a; 2020b; Vysocký et al., 2020; Zubrycki & Granosik, 2014). However, this range has been increased to 80 cm through the new Orion software (Sharma et al., 2018; Ultraleap, 2020b). The Orion software was released for VR in 2016 to improve hand-tracking through many new features, such as improved hand poses, fingertip recognition accuracy and support for greater distances (Leap Motion, 2018; Ultraleap, 2020b).

Figure 3-6 Leap Motion controller.



(a) (b)

Figure 3-7 Visualisation of the (a) real and (b) schematic views of the Leap Motion controller (Weichert et al., 2013).

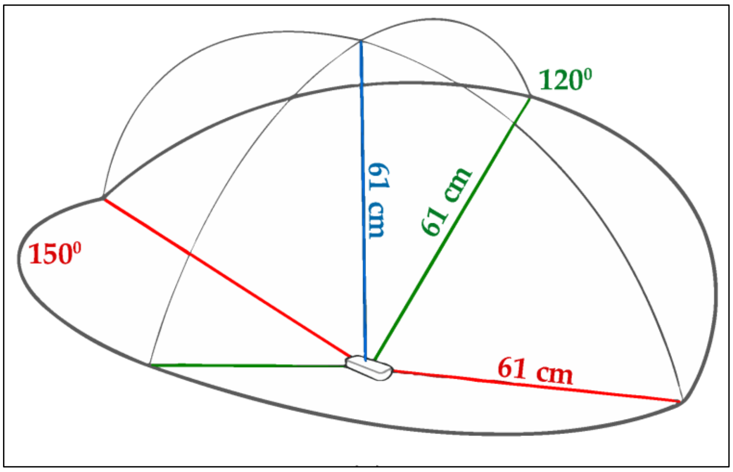


Figure 3-8 Interaction area of the Leap Motion controller (Galván-Ruiz et al., 2020).

In the Leap Motion controller, the sensor data are stored in the local device memory as it reads them. It carries out mandatory resolution modifications and transmits the transformed data via the USB to the Leap Motion software (Bachmann et al., 2018; Ultraleap, 2020a; 2020b; Vysocký et al., 2020; Zubrycki & Granosik, 2014). The Leap Motion controller has an accuracy of 0.01 mm for detecting each fingertip position and a framerate of up to 200 fps (Bachmann et al., 2018; Galván-Ruiz et al., 2020). Weichert et al. (2013) also studied the accuracy and repeatability of the Leap Motion controller. Leap Motion SDK, which is available for various programming languages, such as Python, Javascript, Java, C#, Objective-C and C++, can create applications that acquire the benefits of the Leap Motion controller abilities. Leap Motion improved the software and released Version 4, enhancing the controller's tracking capability (Galván-Ruiz et al., 2020; Leap Motion, 2018; Ultraleap, 2020c).

The Leap Motion controller can recognise position and rotation for two hand objects and perceive 10 fingers with bone-segment composition. Different types of gestures can be recognised, such as the pinch and grab. A pinch gesture is detected when the tips of two fingers touch each other, whereas a grab is recognised when the hand closes to form a fist. These gestures allow users to control 3D objects with a high accuracy level and control various motions using the Leap Motion controller (Rehman et al., 2020; Ultraleap, 2020b). Figure 3-9 depicts gestures recognised by the Leap Motion controller (Yang et al., 2020).

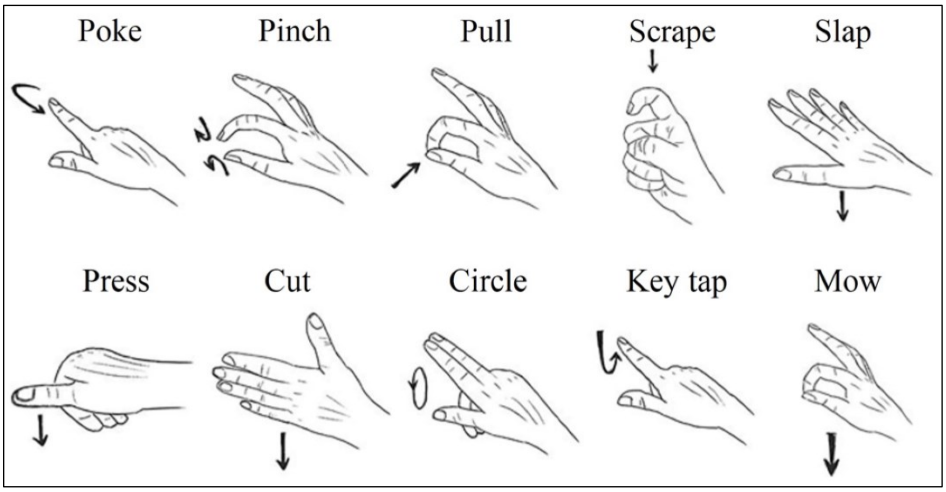


Figure 3-9 Leap Motion controller and hand gestures (Yang et al., 2020).

Another positive characteristic of Leap Motion technology is its affordability. The price of the Leap Motion controller is currently about $89, which explains its increased popularity in diverse fields (Ultraleap, 2020b). Hence, the Leap Motion takes a minimal amount of space, has high precision and sufficiently good performance to be adopted as an appropriate solution (Ameur et al., 2016).

A primary feature of the Leap Motion controller is the appropriate level of abstraction it provides through the Leap Motion application programming interface (API; Ultraleap, 2020c). The API accesses detection data through direct mapping to the fingers and hands. The data obtained through the API are absolute in the sense that the raw detection data used to locate the fingers and hands do not require interpretation by a client application (Potter et al., 2013).

Unity 3D can be used as the main engine for developing Leap Motion applications (Unity Technologies, 2021). Unity 3D supports several programming languages, such as C# and C++. When using C#, the Leap Motion module for Unity uses the Simplified Wrapper and Interface Generator to dynamically convert its function calls (C#) to the native calls used in the Leap Motion API (C++). As soon as the user launches the system, the Leap Motion module begins its tracking process in which the movement of the user’s hand, including the fingers, is recorded as a sequence of snapshots (frames). The software component analyses these frames and sends them to the application as input data. The Leap Motion plugin includes scripts that translate the coordinates from the Leap Motion module to the Unity coordinate system. Unity 3D uses a left-handed convention as its primary coordinate system and metres as its unit of measurement. Conversely, the Leap Motion module uses a right-hand coordinate system, and its unit of measure is millimetres. Thus, the tracking data are transformed internally by the plugin scripts from the right-hand coordinate system to the left-hand coordinate system. In addition, the system internally converts the units of measurement from millimetres to metres (Ultraleap, 2020b).

In summary, the Leap Motion controller is a gesture-based device that provides significant features via its advanced hardware and modern technology. The affordability, compactness, and vast capabilities of the device make it suitable in various fields, particularly in education. The controller can provide new methods of interaction that are more engaging and interactive.

3.4.4.2 Applications of the Leap Motion controller

With numerous advantages, the Leap Motion controller technology is extensively used in many applications. Examples of these include medical and rehabilitation (Guerra et al., 2019; S. Kim et al., 2020; Morando et al., 2018; Nizamis et al., 2018; Placidi et al., 2018; Vivar et al. 2019), musical instruments (Han & Gold, 2014; Hantrakul & Kaczmarek, 2014; Silva et al., 2013), sign languages (Chong & Lee, 2018; Galván-Ruiz et al., 2020; Vaitkevičius et al., 2019), games (Pirker et al., 2017; Yanaka & Ishiguro, 2015), robotics (Bassily et al., 2014; Paparizos et al., 2020; Valner et al., 2018) and education (Nicola et al., 2016; Perdana, 2014; Seif et al., 2017).

Vivar et al. (2019) aimed to compute the tremor intensity using a noninvasive strategy to use the Unified Parkinson's Disease Rating Scale to identify one of the three phases of Parkinson's disease. The Leap Motion controller was used to collect data from 20 patients during rehabilitation exercises by detecting the fingers and palms and measuring 3D coordinates. Different tremor levels were classified in patients with Parkinson's disease, using two statistical features, homogeneity and contrast. Moreover, the interaction between the patient and the Leap Motion controller reduced the patients' discomfort in the clinical evaluation.

Guerra et al. (2019) tested eight 3D gestures commonly identified in previous literature studies using Leap Motion, Atheer and Oculus technologies. The multivariate analysis of variance was applied to the time measures performed by neurotypical patients and patients with Down's syndrome to finalise each gesture and the rate of progress with each gesture. No statistical differences were noted between the two classes of the study in terms of gender or age. Both groups easily performed gestures such as grab, pan, point and stop. Hence, the software programming should consider gestures to develop more inclusive VR and augmented reality (AR) environments. This study proved that VR and AR technologies, such as the Leap Motion controller, can be effective and useful in the daily lives of people with Down's syndrome.

In 2020, S. Kim et al. developed and studied a guide for virtual rehabilitation therapy by tracking the user's wrist joint through the Leap Motion controller and demonstrating its benefits for rehabilitation therapy. The box and block test (BBT) is an assessment technique concerning the upper extremity ability of an adult using blocks (Mathiowetz et al., 1985). In the study (S. Kim et al., 2020), BBT was used to conduct an experiment with 48 healthy participants and compare the developed system using the Leap Motion controller and conventional BBT. No significant difference occurred between the developed system and the conventional BBT, which indicates the possibility of evaluating and diagnosing posthemiplegic stroke patients using the developed rehabilitation therapy guide based on the Leap Motion controller.

A remote monitoring validation engineering system, a home rehabilitation system, was proposed by Morando et al. (2018). This system uses a special rehabilitation technique with the Leap Motion controller and Microsoft Kinect to provide unique interactions for patients. The study involved 41 participants, between 30 and 86 years old, who were hospitalised due to various conditions, including Parkinson's disease, prostheses, fractures and strokes. The rehabilitation system significantly influenced the rehabilitation processes of participants.

Placidi et al. (2018) proposed a process for creating an engineered Leap Motion-based virtual glove, a tool used for accurate calibration and compilation of adequate positioning computations and high-quality positioning error analysis. The virtual glove system was developed to obtain immediate data from two Leap Motion controllers, positioned orthogonally to one another. The results of this research were promising for hand rehabilitation and other applications.

The primary aim of Silva et al. (2013) was to conduct preliminary research and analysis of the potential of the Leap Motion controller to develop new digital musical instruments. The research determined musical gestures that can be identified through the device and analysed the precision and latency of these gestures. Crystal Piano, a virtual music keyboard, was integrated with the Leap Motion controller as part of the evaluation process. The loss and occlusion of tracking issues with the SDK were significant, but the Leap Motion controller proved to be a robust technique to simulate musical instruments.

Hantrakul and Kaczmarek (2014) further explored musical applications by studying the Leap Motion controller regarding effect control and sound synthesis. The Leap Motion controller was integrated with Max/MPS, which is a computer program for making live electronic music performance and integrating it with pre-designed music, to allow motion-based control in a software synthesiser within specified musical parameters. A granular synthesiser was introduced, where users triggered individual grains simultaneously by pressing their fingers mid-air. The authors used the Leap Motion controller features and potentials in music composition and demonstrated the potential of the Leap Motion controller for further exploitation in the music field.

Moreover, Han and Gold (2014) presented the lessons learnt from the evolution of control applications and musical instruments, considering the Leap Motion controller. They designed two musical instruments using the Leap Motion controller: air pads and air keys. Several melodies were played to test and evaluate the presented prototypes, demonstrating that the Leap Motion controller can be used effectively in musical applications.

Chong and Lee (2018) tested the recognition of the complete ASL, consisting of 10 digits and 26 letters, using the Leap Motion controller. Two classification methods were used and compared, finding that the letters were classified with a high degree of accuracy.

In addition, Vaitkevičius et al. (2019) proposed a system in which the Leap Motion controller was used to track and recognise the user's hand positions. The data were used to identify the appropriate gestures in a VR environment. Twelve participants performed 24 gestures analogous to the ASL letters. The gesture for each letter was executed 10 times to obtain 2,880 data samples. The gesture-recognition accuracy was 86.1 ± 8.2%, and the typing speed of the gestures was recorded at 3.09 ± 0.53 words per minute when gestures were recognised for ASL.

Pirker et al. (2017) explored the Leap Motion controller as a gesture-based, controlled-input device for computer games, combining gesture-based interactions into two game setups to investigate the suitability of the controller in entertainment. The results indicated potential in terms of training efforts and user engagement for short-term experiences.

Bassily et al. (2014) adopted and implemented a uniquely adaptive and intuitive scheme by designing a machine-human communication interface between the 6 DoF Jaco robotic arm and the Leap Motion controller. They developed an algorithm that maps the hand gestures identified via the Leap Motion controller and the Jaco arm with optimal results. The implementation would improve the quality of life, specifically for individuals with upper limb issues, helping them execute basic, everyday activities.

Lu et al. (2017) presented a virtual switch system using the Leap Motion controller, consisting of five switches to virtually control an electric fan and bulb. This system could help people who have difficulty operating switches with their hands.

Paparizos et al. (2020) developed a remotely controlled mobile robot system that provides the benefit of isolating a patient from medical staff, especially in the case of a pandemic breakout. The Leap Motion controller could be more user-friendly and noninvasive than joysticks, gloves or the Microsoft Kinect. The feedback from the lab assistant indicated that less than a week of training would be required for young adults with technology experience. However, its drawbacks include a limited range and operating time. This approach would best fit a teleoperated hospital assistant to minimise cost, which is still not identified as standard medical equipment.

These study results present the potential of the Leap Motion controller, which has attracted many researchers to explore and investigate its usage and benefits in different applications. The controller has been studied in fields such as entertainment, medical, health care, education, sports and communication, and the preliminary results are quite astonishing. These studies demonstrate the need to continue developing more critical and valuable applications essential in life, such as education and skills training. This work aims to support research and increase the applications of the Leap Motion controller to activate its role in various fields and increase its efficiency. This aim is achieved using the Leap Motion controller in an education application for secondary school.

3.4.5 Gesture-based applications in education

Many research studies have effectively used gesture-based technology in numerous fields, as discussed above. Much research has been conducted to investigate and examine the effects of using gesture-based technology in the education field in different majors, such as the following:

- chemistry (Alsayegh et al., 2013; Schönborn et al., 2014),
- anatomy (Al-Razooq et al., 2017),
- music (Baratè et al., 2019; Perdana, 2014),
- language (Yükseltürk et al., 2018),
- biology (J. Lee et al., 2013),
- physics (Gimeno et al., 2014; Hsieh et al., 2013),
- engineering (Y. Chang et al., 2014),
- special education (Hu & Han, 2019),
- surgical simulation (Caligiana et al., 2020; Ferreira et al., 2020),
- medical training (Lahanas et al., 2017; Nicola et al., 2016; Seif et al., 2017; Umeda et al., 2017), and
- learning tools (Kellerman et al., 2018).

This section reviews research studies on the effectiveness of using gesture-based technology for educational purposes and their results.

Alsayegh et al. (2013) developed a virtual environment to allow the user to discover the landscapes of complex energy and interact with an open-source molecular visualisation system, Jmol (n.d.), using hand gestures. The prototype consisted of the Microsoft Kinect platform and computer vision library, OpenNI (Occipital, 2021). Hand gestures were analysed and translated into specific instructions in real-time to handle molecular structures on the interface. The integration process between Jmol and Kinect was successful and can be employed in building new materials. Therefore, in this virtual environment, the molecules could be manipulated efficiently using hand gestures, which improve the user's understanding of chemical interactions and the landscapes of complex energy.

Al-Razooq et al. (2017) investigated the usability of the Leap Motion controller and studied an educational application aimed to compare and contrast the hearts of three animals. An experiment was conducted in which six students were selected to carry out two tasks. The first task was to explore the heart anatomy of a cat, and the second task was to take the quiz. The results indicated that participants faced an issue regarding which gesture to use, and it was difficult for them to understand the sequence of gestures. However, the participants stated that they needed additional time to comprehend the gestures. They were also willing to use the Leap Motion controller as an interactive device in the future.

Baratè et al. (2019) examined the effect of the Leap Motion controller on the musical expression of impaired people and primary school children. The developed application allows a user to move the hand up and down and play the musical instrument virtually via the Leap Motion controller. A class of 18 students in the third grade was divided into two groups. The first group used the virtual instrument freely, whereas the second group was asked to perform simple music tunes presented in labelled note names and a corresponding interface colour. The second group of students performed better than the first group of students, and it also helped foster interaction. A similar experiment was conducted in a rehabilitation centre. The patients' interaction was also positively affected by using virtual music in a therapeutic session.

Perdana (2014) proposed new software for music education using the Leap Motion controller, comprising performance and game applications. In the first application, students were asked to execute a specific music piece using two hands. In the second application, students could play music and practise their hand movements accordingly. This study tested the software with school students in Malaysia and evaluated their experience using a survey. The students were interested in the music game but found it challenging, so training was necessary to use the software.

Yükseltürk et al. (2018) developed a game-based English language learning software using the Kinect and analysed its influence on the attitude and self-efficiency beliefs of students in terms of learning English. The system was developed to provide an active learning environment to allow interaction using Kinect technology. An experiment was conducted in which control and experimental groups were formed in the foreign language course for first-year students at a university in Turkey. The results indicated no significant difference in the pretest in the control and experimental groups. However, after the inclusion of game-based learning, a positive attitude was observed in students towards learning English in the experimental group. The study indicated that students were motivated to learn a foreign language with the game-based method, and it also affected the self-efficiency, beliefs and attitudes of the students in a positive manner.

In 2013, J. Lee et al. developed a gesture-based system for interactive manipulation of 3D objects in the Molecule Viewer tool using Microsoft Kinect. Molecule Viewer is a 3D visualisation educational tool used to discover and understand DNA structures and protein molecules typically used by instructors and students. In the developed system, hand gestures and positions were recognised using Microsoft Kinect and transformed into control commands for manipulating 3D structures. The developed system was tested in a regular classroom environment where the user was 1.2 to 1.6 m away from the Kinect, and each gesture was repeated 100 times. The results indicated a 90% accuracy rate in recognising the gestures for the developed system. The authors anticipated that the developed system could be used for HCI, particularly when users are away from the keyboard or mouse or cannot use their hands.

Gimeno et al. (2014) introduced a learning strategy to recreate a commercial MEMS design in a professional environment. This study was conducted at the University of Zaragoza for students enrolled in a micro and nanosystems course to learn the basic technical skills to analyse, design and simulate small and microsystems and the principle of basic manufacturing processes. The Wii Remote was used as part of the course activities due to its popularity as a gaming device that involves creating communication methods. According to the researchers, all designed learning activities assisted in comprehending the physical phenomena behind the operation of MEMS in a better manner using visual explanations. Furthermore, using particular simulation and design tools results in the development of expertise associated with MEMS.

In 2014, Y. Chang et al. developed a virtual platform for mechanical assembly education using gesture technology, the Kinect sensor. The students could perform assembly tasks, such as picking, placing and attaching parts and manipulating them using a single hand or both hands. The assembly platform recognised voice commands, and procedures were performed collaboratively by multiple users. The preliminary study results indicated that, with the help of instructors, the mechanical engineering students could fulfil the basic assembly tasks successfully. The proposed system provides an affordable platform to enhance the learning of mechanical engineering students.

Hu and Han (2019) studied the effectiveness of a gesture-based instruction program developed using the Leap Motion controller to teach school students in China living with autism spectrum disorder (ASD) matching and task management skills. The match-to-sample procedure is a task to teach matching skills to a student with ASD to develop visual discrimination skills (MacDonald & Langer, 2017). The program had 120 3D pictures familiar to the students (Hu & Han, 2019). The experiment was conducted on three students, and the results indicated a low level of task management and correct responses in the baseline phase, where students matched the samples independently. The correct responses increased in the intervention phase, where teachers provided instructions, and the maintenance phase, where a spotlight for correctly matching 3D pictures was presented.

Teaching with the gesture-based technology increased task management and match-to-sample skills after three weeks in children with ASD. However, the study limitations include the limited sample size, performing the experiment in one classroom setting, and being limited to a single match-to-sample program.

Caligiana et al. (2020) presented a solution to simulate surgical procedures by cutting and modifying hands-free virtual objects. This surgical mixed-reality application was developed using the Microsoft HoloLens viewer and Leap Motion controller to recognise hand gestures. A case study was used to test the usability and efficiency of the application using a digital model of a foot bone from a computerised tomography (CT) scan. The results indicated that the foot, which is complex and contains many bones, was cut successfully in a short time compared to the original method. One limitation was that textureless, shiny, and light objects were difficult to track.

Ferreira et al. (2020) analysed the usage of the Leap Motion controller as a tool for capturing hand and finger movements in a simulated hysteroscopy using a hysteroscopy 3D printed model. An animation blender and computer modelling software were used to model some hysteroscopy elements, such as a hysteroscope with a resectoscope, sessile and pedicled polyps, and the uterine cavity. The downward/upward and leftward/rightward movements simulated by the VR system were satisfactory. However, forward/backward movement accuracy was reduced due to pinch gestures when the distance from the Leap Motion interaction box increased. Overall the results were satisfactory, and the system will be valuable in developing surgical simulators using gesture-based technology, such as the Leap Motion controller. The lack of haptic feedback, the noise, and the inability to capture movements from different body segments were the study limitations.

Lahanas et al. (2017) analysed the potential associated with a VR simulator based on the Leap Motion controller for basic laparoscopic skills assessment. Bimanual operation, instrument navigation, and camera navigation were the three basic developed tasks. Two stimulation centres, in Saudi Arabia and Greece, were used to conduct the experiment. The participants were divided into two groups, one with 21 novice surgeons and one with 28 expert surgeons. The expert surgeons performed better in instrument navigation and bimanual operation in all performance metrics, path lengths, errors and time. However, for camera navigation, a significant difference was found in the disorientation metric. In conclusion, the system provides the opportunity of assessing and training basic laparoscopic skills at a lower cost.

A medical system to convert a 2D image of a CT scan from the Digital Imaging and Communications in Medicine format to the 3D Object format was proposed by Seif et al. (2017). The system uses the Leap Motion controller as input for interacting with its interface. This medical training system is aimed at interns and medical students. An experiment was performed in which CT data of the heart was chosen because it requires a high level of accuracy in surgery. The object of the heart could be grabbed by the user using one hand, then analysed from several viewpoints and explored inside.

Kellerman et al. (2018) investigated an affordable substitute of the chalkboard, transparent slides, and passive PowerPoint slides using the Nintendo Wii Remote combined with a developed whiteboard software. This approach aimed to provide a cost-effective method of teaching that increases student attention and enhances lecturer efficiency. The developed system provided different features, such as pen and drawing tools and writing and colour options. The system has the required functionality to improve education through technology and assist teachers and students in classrooms. The system was user-friendly and did not require extensive training. The lack of an eraser in the image editor and the unavailability of additional options to solve line-of-sight obstructions were the system limitations.

Accordingly, many researchers have studied gesture-based devices, such as the Microsoft Kinect and the Leap Motion controller, in education for different purposes. The use of gesture-based devices was investigated in mostly practical activities, and nearly all of them focused on the design and implementation of educational software. The contribution of most of these studies lacks experimental methods conducted in an educational setting. Further, most of the research studies were intended for university students and professionals in highly specialised topics. Nonetheless, gesture-based technology, particularly the Leap Motion controller, has yet to be examined and studied in other educational areas.

3.5 Chapter Summary

This chapter reviewed the subject of HCI with a focus on gesture-based interfaces. Gesture-based input devices are developed using either vision-based or contact-based methodologies. Vision-based devices rely on the identification of hand movements and gestures by capturing and analysing video sequences. Contact-based devices detect input actions through physical contact, such as an accelerometer, data glove or multitouch screen. In general, vision-based gesture-recognition devices comprise three primary components: gesture modelling, gesture analysis, and the recognition stage. The Leap Motion controller is a recently introduced vision-based device that recognises hand gestures and movements with a high degree of accuracy. It has many applications in various fields, such as the entertainment, medical and rehabilitation industries. Different gesture-based devices have been studied and analysed in many educational fields, and this area of research is continuing to grow.

Chapter 4. RESEARCH METHODOLOGY

4.1 Introduction

This research aims to study gesture-based technology, the Leap Motion controller, and the combination of the two concepts, simulation and molecular visualisation, in chemistry education. Therefore, this work introduces and studies a chemistry educational system for secondary school students that uses gesture-based technology and combines simulated experiments and molecular representation to achieve the research objectives. The basic concepts and methodologies of this research were established to achieve these objectives based on the fundamentals of scientific research.

This chapter presents and discusses the methodologies of testing the educational system, including the research strategy, methods and procedures used to study the system and examine the research hypothesis. The research uses three methods: the interview study, usability testing, and experimental study. The procedures, data collection and analysis methods are discussed for each research method.

4.2 Research Experiment Methodologies

The development of methods and techniques already used in general education and particularly in science education is the basis for the proposed educational system, which combines simulation and molecular visualisation. This system, which combines two different concepts and uses a gesture-based device, the Leap Motion controller, is expected to improve learning outcomes over traditional teaching methods. As a result, this research studies the effectiveness of this system for secondary chemistry students and its ability to improve learning achievements and tests its usability. Thus, this section discusses the methodologies applied to assess the research hypothesis and meet the research objectives.

The research strategy design and selected methods for this experiment are explored in this section, which also details the qualitative and quantitative data collection and analysis methods used in this research.

4.2.1 Research strategy

A mix of quantitative and qualitative methods and a triangulation strategy were selected to achieve the research objectives and assess the hypothesis. The research includes a qualitative method (interviews) and two quantitative methods (usability testing and experimental study). The triangulation strategy uses more than one method to validate and confirm results and guarantee their accuracy. In mixed-method research, several data sources and methods to attain a broad understanding of the research question are used in triangulation (Olsen, 2004). A mixed-method approach incorporates qualitative and quantitative research to collect and analyse data within the same study (Molina-Azorin, 2016). In qualitative research, data are collected by interviews, observations, and other methods. In contrast, quantitative research collects data through surveys and experiments (Creswell & Creswell, 2017). The mixed-method approach is frequently used to validate results obtained from another method, examine the research question from a different angle or elucidate contradictions or unexpected results (Creswell & Creswell, 2017). In addition, mixed-method research is used to generalise results obtained from qualitative research. The mixed-method approach in research related to any subject helps develop that field and enrich the understanding of the associated questions and problems (Creswell & Creswell, 2017).

Mixed-method research was used in this research study to employ its advantages. As a result, it leads to a better understanding of the research problem and related topics, such as examining gesture-based technology in education, improving the teaching of microscopic chemistry concepts, and developing the features of virtual laboratories. Mixed methods also enable assessing the research hypothesis from different perspectives for students and teachers. As a result, the research hypothesis can be validated, and the results can be confirmed and generalised.

Accordingly, three phases were applied to assess the hypothesis in this research, as presented in Figure 4-1:

- First, the interview study investigated the effectiveness and usability of this system in chemistry education from the teachers' perspective.
- Second, testing assessed the interface design of the system and its usability.
- Third, the experimental study investigated the effect of the proposed educational system in chemistry education and student learning achievements.

The methodologies of these three research methods are discussed below.

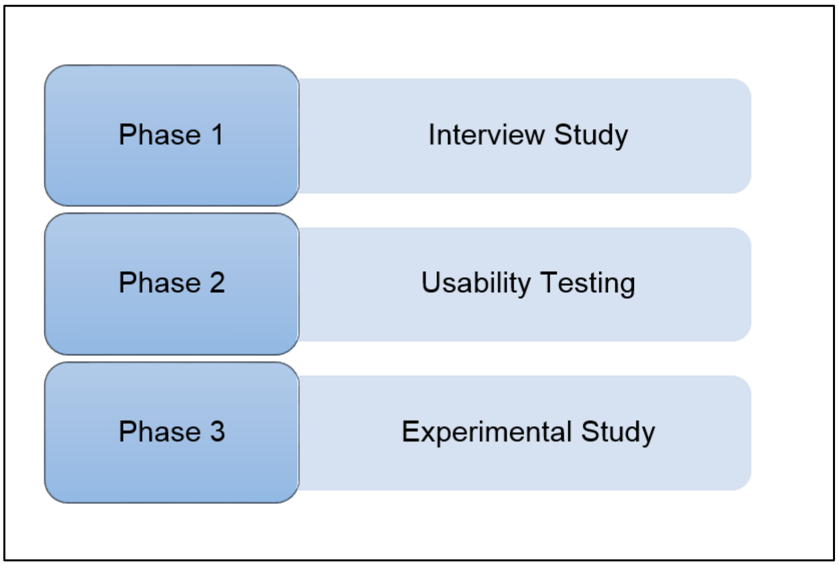


Figure 4-1 Phases of research methods.

4.2.2 Interview study

The first phase of this research to study the presented educational system comprises individual semi-structured interviews with several chemistry teachers. These interviews were conducted after developing the proposed educational system. They are different from the requirements interview, which was conducted before developing the system to determine the system requirements and is detailed in Chapter 5.

In this phase, the interviews were conducted at the beginning of the process to detect the effect of this system on chemistry learning and assess the system usability. This study is presented and detailed in Chapter 6. Interviews were conducted to gain the respondents' perspectives and acquire in-depth knowledge regarding particular phenomena (McNamara, 2006). In this study, the face-to-face, individual, semi-structured interview style was used due to differences in opinion and experiences between the respondent teachers and the need to be responsive to them. The interview questions were designed to concentrate on specific topics and were designed according to the participant responses, aiming to correspond to their answers throughout the interviews.

The semi-structured interview was selected because it is an intelligible and flexible approach that allows respondents and researchers to discuss a topic or question in detail. It is an effective approach for gathering information if the respondent finds it difficult to answer specific questions or provides only brief answers, allowing the interviewer to prompt the respondent to elaborate further (Qu & Dumay, 2011; Ryan et al., 2009). In addition, the individual interview is selected because it helps researchers analyse nonverbal cues, observing facial expressions, body language and eye contact. The individual interview may also help the researcher better understand the individual's responses and explore the meaning hidden in an individual's response (Ryan et al., 2009).

4.2.2.1 Sampling

The interview study used convenience sampling. The interviewees were five chemistry teachers, which was the number of available teachers, and it was difficult for a sole researcher to interview numerous participants. Convenience sampling is the most commonly used sampling type, where participants are asked to participate in a study because they are available in terms of willingness, time, location and access. With convenience sampling, the researcher can rapidly and easily gather the sample needed for research (Lopez & Whitehead, 2013).

4.2.2.2 Data recording and collecting

In this study, qualitative data were gathered through the interviews. To collect useful data, the interviewer interviewed the respondents comprehensively and systematically and kept the respondents on track. The interview questions consisted of a core question and linked subquestions. Written notes were taken on the interviewees' impressions and reactions while using the educational system. In addition, the interviewees' responses were recorded in writing during the interviews. Each interview lasted between 45 and 60 minutes and was conducted and transcribed in Arabic and then translated to English.

4.2.2.3 Data analysis

A qualitative analysis of all questions was conducted (Y. Zhang & Wildemuth, 2009) according to the phases recommended by Creswell (2012; Creswell & Creswell, 2017) to formulate the data, comprehend the subject matter, learn about differences, illustrate the simple findings and investigate all complications. A visual model of the coding process in qualitative research is presented in Figure 4-2. The NVivo 10 computer software was used to organise and generate the themes in the current research and code teachers' interview data during the analysis process (R. B. Lewis, 2004; QSR International, 2021).

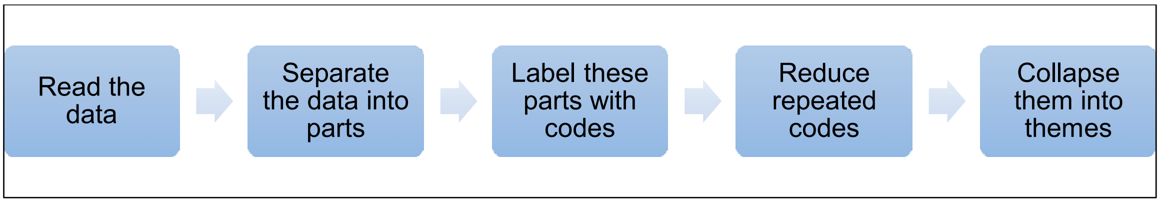


Figure 4-2 Visual model of the coding process in qualitative research.

4.2.3 System usability testing

Usability testing is the second phase of this research to study the presented educational system. Before the experimental study, usability testing was conducted to evaluate and study the system interface and the design and presentation of the information and knowledge. This study is presented and detailed in Chapter 6.

Usability testing is a technique in which the product, equipment or service is tested on the users. Usability testing evaluates the effectiveness, efficiency and satisfaction of the user with the system under testing (J. R. Lewis, 2012). One advantage of usability testing is that it obtains a direct response from the target audience (Rubin & Chisnell, 2008) and enables opinions, emotions, and conative and cognitive effects to be observed (Moritz & Meinel, 2010).

4.2.3.1 Design

The overall design of the usability testing process is crucial and must involve predefined procedures, where the sequence of actions defines the validity and strength of the outcomes. In this study, quantitative data were gathered through testing. The survey used in this study includes two sections: demographics and the body of the questionnaire. In the first section, a brief background questionnaire was completed by the participant. Then, a user satisfaction questionnaire rates the system and gathers quantitative data using a 5-point Likert scale (from strongly disagree to strongly agree) for 13 subjective measures.

The process of designing test questions began with scanning and careful reading (Bangor et al., 2008; R. Lewis, 2012; Rubin & Chisnell, 2008; Sauro & Lewis, 2012). After thorough research, these measures were established based on the procedure proposed by J. R. Lewis (2012) for the usability test design. The main features to be evaluated were identified and organized. For standardized questionnaires, the System Usability Scale (SUS) is a widely used questionnaire (Brooke, 1996). Thus, the SUS questions were modified and derived to cover the proposed system requirements. Finally, the measures were identified to achieve the test objectives.

4.2.3.2 Sample

Convenience sampling is used in usability testing because it enables fast and accessible data collection, and the sample size can be reached easily. A sample of 90 female students was contacted and recruited voluntarily for usability testing at Princess Nourah bint Abdulrahman University (PNU). This large number of participants ensures stable results. Because PNU is a university for females, the participants were of the same gender. This affected the diversity of the sample and may have potential limitations. However, it was a convenient choice for the researcher to gather a sufficient number of participants with the appropriate ages and experiences to conduct the study. Nevertheless, the results of this study will present new opportunities for further research regardless of the sample diversity.

4.2.3.3 Data analysis

The goal of data analysis in quantitative analysis is to obtain meaningful data from raw numbers using rational and critical thinking. As a result, descriptive statistics were used to analyse data, summarise data and identify patterns in the quantitative research (Creswell & Creswell, 2017). In usability testing, the mean rating and percentage of agreement were used to analyse and interpret the quantitative data.

An inferential statistical test (t-test) was used to compare the system usability testing results of each input device, the Leap Motion controller and the mouse, for each measure. A t-test is an inferential statistical test used to compare the means of two groups to determine if there is a significant difference between them (Wadgave & Khairnar, 2016; Xu et al., 2017). The statistical package for social sciences (SPSS) from IBM supports advanced statistical analysis mechanisms (IBM, 2020). The SPSS was used in this phase to analyse the usability testing data.

4.2.3.4 Validity and Reliability

The validity and reliability were evaluated to confirm the quality of the usability testing. Validity ensures the integrity of the conclusions, while reliability is concerned with the consistency of the defined measures (Bryman, 2016). Establishing the validity and reliability of the results is an important aspect of any research. The extent to which the scores from a measure represent the variable for which they were designed is known as validity (Saunders et al., 2009). In the usability testing, the responses from participants were obtained through an anonymous questionnaire based on a 5-point Likert scale. To ensure the validity of the results, the questions are designed in a way to make it easy for participants to understand using words that are unambiguous and common. Validity implies that the obtained data are meaningful and understandable, which allows a researcher to arrive at a valid conclusion.

Regarding the reliability of the measured construct, it is said to be reliable when it is consistent and stable under different conditions such that it represents the common opinion (Carlson et al., 2009). The reliability of a study is an important characteristic of a study to reduce error and bias of the results. There are different methods for testing reliability, such as internal consistency, test re-test and alternative form (Mitchell 1996). In the usability testing, the internal consistency was evaluated using Cronbach's alpha test, which describes how well all items measure the same concept. When such value is relatively high, it indicates a high degree of internal consistency.

4.2.3.5 Survey Bias

The results of a study can be negatively impacted by survey bias, which occurs when it is calculated in a different systematic method, a modified method according to research conditions, than the estimated method, a predefined and consistent method. There are many types of survey bias, such as sampling bias, non-response bias and questionnaire bias (Fowler, 2013). In this study, a standard research method was used to avoid bias and ensure validity and reliability. Consequently, the study was designed based on the procedure proposed by J. R. Lewis (2012) for the usability test design.

Sampling bias occurs when a certain type of population is selected while ignoring others (Krumpal, 2013). In this study, even though all the samples were female, it attempted to avoid bias and reduce targeting through the collection method. Accordingly, the participants were from PNU where the population is diverse to ensure demographic diversity in different factors, including age, education level, computer skills and e-learning experience. In addition, this study used a large sample number, ensured participants' confidentiality, and respected participants' time by making the time commitment small. These considerations ensure stable results and help increase the response rate to improve the possibility of a well-representation of the target population (Saleh & Bista, 2017).

Moreover, non-response bias occurs when some participants do not respond or answer some of the questions. The non-response bias is increasingly affected by the low response rates (Peytchev, 2013). In this study, participation in the survey is voluntary, which makes the study unbiased because there are zero non-respondents.

Further, questionnaire bias, also known as response bias, occurs when the different conditions and biases can influence responses, which can negatively impact the results of a study (Althubaiti, 2016; Szklo & Nieto, 2014). Response bias can be avoided using many methods, such as making the survey anonymous, to prevent or reduce its impact on the validity of a study (Fadnes et al., 2009; X. Zhang et al., 2017). Thus, the users are informed about the anonymity of the survey and interviews to avoid or minimise response bias.

4.2.4 Experimental study

The experimental study in this research aims to examine the effect of the presented educational system and study the ability of secondary students to acquire knowledge from the system. This approach was selected to assess the effectiveness of the system in learning chemistry. This study is presented and detailed in Chapter 7.

In the experimental study, the researcher manipulates an independent variable and monitors and controls the changes occurring in dependent variables. The researcher observes and measures any changes in the groups after receiving the treatment (Leedy & Ormrod, 2016). An advantage of experimental research is that a high level of control is given to the researcher. The researcher forms an idea about the results in the early stages and detects causal relationships (Ross & Morrison, 2008).

4.2.4.1 Design

Because only a convenience sample is possible and the groups (the classes) are naturally formed, a quasi-experimental design was selected for this research (Creswell & Creswell, 2017). The quasi-experimental design used for both pretests and posttests, known as the nonequivalent control-group design (Creswell & Creswell, 2017). In the following diagram (Figure 4-3), the classic notation system by Campbell and Stanley (1963, p.7) was used.

Group A O____________X1____________O

Group B O____________X2____________O

Group C O____________X3____________O

Group D O__________________________O

Figure 4-3 Diagram of the design used in the experimental study.

The experimental Groups A, B, C and control Group D were selected without random assignment. All groups underwent a pretest and posttest O. Treatments X1, X2 and X3 were administered to the experimental groups. In this study, pretests were administered to four classes. Different treatments were applied to three classes, whereas the fourth class represented the control group.

This experiment was applied twice with different content and different pretests and posttests. While the two experiments used the same four classes, they alternated between classes in each case to guarantee that no participant received the same treatment twice. The researcher designed and supervised the experiment, while the pretest and posttest were developed by the chemistry teacher for all four classes that conducted the experiment.

4.2.4.2 Sample

This study used convenience sampling to select 113 secondary school students in four classes. All participants were female because the research was conducted in a public secondary school for girls in Saudi Arabia, and their average age was 17. Since the students were of the same gender, this might have potential limitations. Because schools in Saudi Arabia are single-sex and the researcher is female, the convenient option was to conduct the study in a female school, regardless of its effect on the diversity of the sample.

4.2.4.3 Data analysis

In this experimental analysis, different types of statistical analyses were used during the experiment to evaluate and interpret the quantitative data. Descriptive statistics, including the means and standard deviations of the test scores, were calculated at the pretest and posttest stages of the two experiments to observe and measure the results. As a descriptive statistic of the random sampling process, the standard error of the mean was calculated to estimate the variation between the sample and population.

An inferential statistical test was used to analyse the experimental study results and examine the study hypotheses. The main effects of the conditions on the dependent variable were compared using a one-way analysis of variance (ANOVA). For statistical hypothesis testing, post-hoc comparisons using the Bonferroni correction were applied to define significant differences in the dependent variable between groups. The SPSS was used in this phase for the statistical analysis of the experimental study data (IBM, 2020).

4.3 Chapter Summary

This research presented and studied a chemistry educational system using gesture-based technology (the Leap Motion controller), integrating simulation and molecular visualisation for secondary school students. This chapter discussed the research strategy and design, including qualitative and quantitative research designs. The research design was based on an experimental study, and its methodologies, procedures, data collection and analysis methods were discussed. In addition, the research included interviews and usability testing. The specifications of these methods and their design, sampling, data collection and data analyses were presented in this chapter. In the following chapters, an explanation of the proposed educational system and different research methods is comprehensively presented.

Chapter 5. PROPOSED EDUCATIONAL SYSTEM

5.1 Introduction

Teaching strategies based on auditory and visual cues are traditional in the educational field. However, researchers have recently investigated different techniques for teaching that use advances in technology to convey information. The previous research and projects were studied to investigate the effect of using technology in education and the difficulties facing students in learning chemistry. This research seeks to develop an educational system for learning chemistry through simulations of experiments and visualisation of molecules, using the Leap Motion controller as an input device with a 3D GUI. Thus, the proposed system integrates the macroscopic and microscopic levels with the gesture-based interface to overcome the limitations of the available educational systems.

This chapter outlines the system development life cycle. Before developing the educational system, identifying the user requirements is essential in ensuring the system's contribution to the educational process. These requirements are acquired by studying previous research and interviewing chemistry teachers and students. This chapter introduces the teachers' interview process to gather the user requirements and discusses the methodologies and findings. The next section examines the concepts of developing the chemistry education system for secondary school. It discusses a gesture-based device, the Leap Motion controller, as a concept of this system. This system combines simulation and molecular visualisation; thus, these two concepts are also studied in this section. Further, this chapter presents the system description and development process, including the analysis, design and implementation phases. The system specifications and description were published in (Aldosari & Marocco, 2015a; 2015b; 2016; 2017).

5.2 The Proposed Educational System Development Life Cycle

The system development life cycle is a process for planning, designing, creating and testing a system. There are various system development life cycle models that comprise a set of defined phases (N. A. Khan, 2021, Shylesh, 2017). The development life cycle of the proposed educational system is composed of five phases (see Figure 5-1):

1. **Identifying Problems and Planning**

This is the initial phase in which the proposed educational system objectives will be determined and a high-level plan for the research will be established. It includes activities for getting feedback from target users to determine their needs. The scope of the system is also defined in this phase. Accordingly, Chapter 2 studied the challenges of teaching chemistry and using computer technology in education. Chapter 3 studied gesture-based technology and its applications. A teachers' interview study is conducted to define the system requirements (see Section 5.3). Then, the system concepts are detailed in Section 5.4.

2. **Analysis**

In the analysis phase, the requirements are thoroughly acquired based on the information gathered during the initial phase. In particular, the requirements are defined, which specifies what the proposed educational system must do. The system analysis phase is presented in Section 5.5. It includes defining the user characteristics, functional and non-functional requirements.

3. **Design**

In the design phase, the system design is prepared, which specifies hardware and system requirements, such as data layers, programming languages, operating system and user interface. It helps define the overall system architecture. The system design phase is presented in Section 5.6. It includes defining the architectural design and design rationale.

4. **Implementation**

The actual development of the system is done in this phase, where the code is written according to the system's design. Section 5.7 provides a description of this phase, the applications, and the programming language used to implement the proposed system.

5. **Testing**

In the last phase, the proposed educational system is tested using test cases to check for errors or system defects and verify it performs as expected. This phase is important to verify that the system works according to the specified requirements.

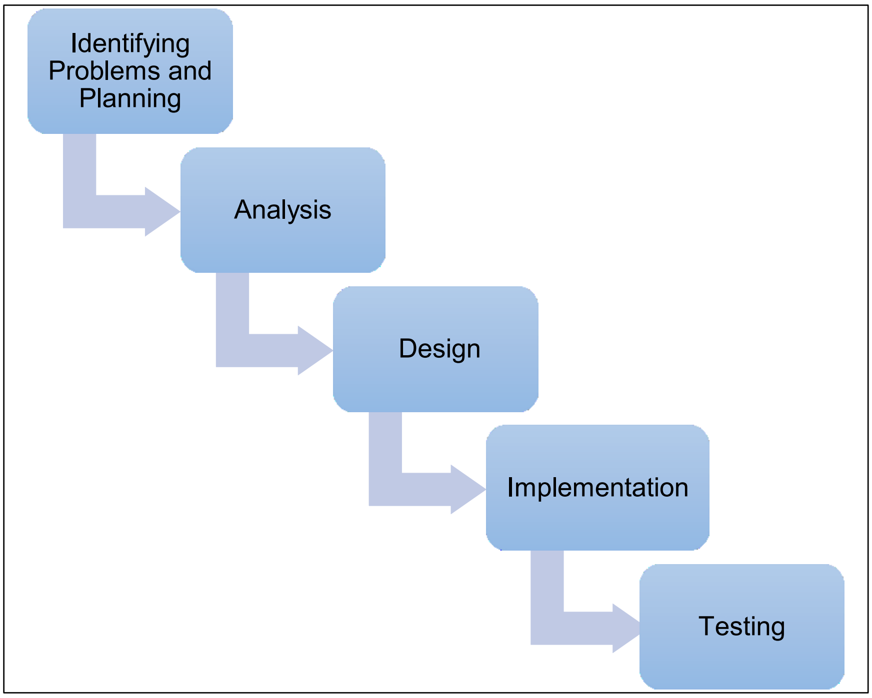


Figure 5-1 The proposed educational system development life cycle.

5.3 User Requirements

To design an educational system for the secondary school level, determining the user requirements is a critical phase of the system analysis. These requirements must be defined carefully to ensure system quality, meet user needs, and reduce uncertainty. After studying previous research on the challenges of teaching chemistry and using computer technology in chemistry education, interviewing chemistry teachers who need an educational system is essential. The interview study aims to define their requirements as system users. Therefore, a small group of teachers was interviewed to identify these requirements and the difficulties they face. This study attempts to derive, define, classify and detail all user requirements.

5.3.1 Participants

It is crucial to interview teachers and students, to design an educational system for school students. Interviewing teachers is more beneficial, as they have the scientific knowledge and experience in teaching chemistry in schools. Their feedback will provide valuable information to determine the difficulties they face, analyse their causes and identify the user needs.

The interviewees were two chemistry teachers with bachelor's degrees and experience in teaching secondary school chemistry in Saudi Arabia. The first teacher has 12 years of experience teaching secondary school chemistry, whereas the second teacher has six years of experience teaching secondary school chemistry. The teachers are referred to as Participant 1 and Participant 2, respectively, in the following sections.

The sample size was chosen based on teachers' availability, as their consents were difficult to obtain. However, adequate information was collected, and additional time was devoted to interviewing them and analysing their feedback. In contrast, the students were not interviewed, as it was much more difficult and required complex protocols. Therefore, the participation of students was postponed to the experimental study, which included 113 students.

5.3.2 Methodology

The study was designed using qualitative interviews with teachers regarding their experiences in teaching chemistry. The semi-structured group interview was held at the respondents' office and was conducted face to face in a friendly and welcoming manner. The interview lasted about one hour after obtaining permission from the interviewees. The interview framework was designed based on the following topics:

- identifying problems related to teaching the macroscopic and microscopic levels in chemistry experiments,
- defining the user environment and identifying potential solutions,
- defining user requirements for the macroscopic level of chemistry experiments,
- defining user requirements for the microscopic level of chemistry experiments, and
- identifying the general user requirements and determining system specifications.

The interview questions are available in Appendix A, and the interview transcripts are in Appendix B.

5.3.2.1 Data analysis method

The interview responses were transcribed during the interview. Then, all responses were analysed using qualitative analysis (Y. Zhang & Wildemuth, 2009). This analysis was based on the procedure Creswell (2012; Creswell & Creswell, 2017) suggested to organise and formulate all data, realise the subject matter, recognise differences, and determine conclusions and implications. After scanning and careful reading, the main ideas and concepts were identified, coded and organised. Next, the themes in the data were built, and multiple modifications were made. Finally, the findings were concluded.

During the formulation process, the following main subject matters were identified. First, teachers' previous experiences in teaching the microscopic and macroscopic levels in chemistry experiments, including problems and their solutions, were identified. In addition, the general user and system needs were determined, as presented in Figure 5-2. NVivo 10 was used to define, categorise, and analyse the interview themes and codes (R. B. Lewis, 2004; QSR International, 2021).

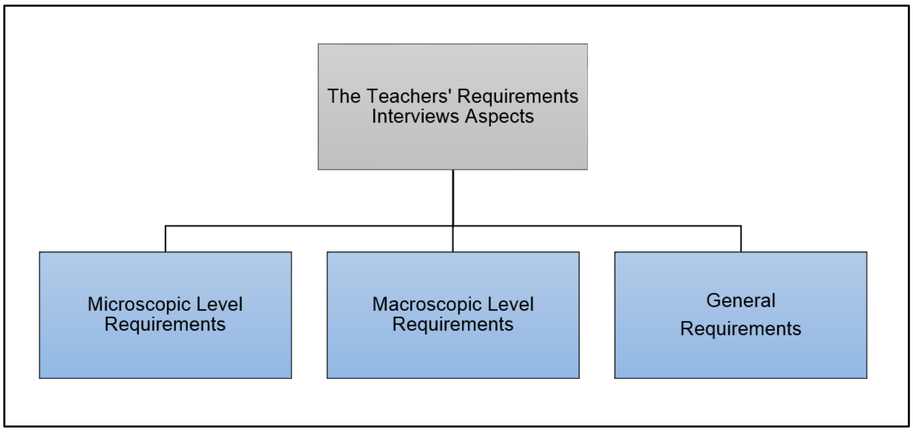


Figure 5-2 Main themes of the teachers' interview.

5.3.3 Results

The results of analysing the interview were classified into three categories: microscopic level, macroscopic level, and general requirements. These results are discussed next.

5.3.3.1 Microscopic level

Both interviewees reported that one of the most critical problems they face in chemistry teaching is student understanding of chemical equations and molecular structures of compounds. They commented that most students have difficulties imagining the molecular structures of chemical formulas and understanding chemical interactions involving the cleavage and formation of chemical bonds because they are based on abstract and intangible concepts. Participant 2 stated that teachers use ready-made images and board drawing of molecular structures to try to overcome these obstacles. However, they reported that these solutions have some disadvantages, such as the difficulty of covering all the molecules and providing sufficient details about them. Participant 1 indicated that, at the intermediate level, teachers use molecular models to illustrate chemical compounds and concepts. She clarified that this method could not be applied at the secondary level because it is a costly method, and the studied chemical compounds are more complex and numerous. Participant 1 stated that the available educational systems only display the final chemical compounds without providing interactions and procedures. They approved their need for an educational system that visualises chemical compounds in 3D before the chemical reactions. They also expressed their need for a system that displays chemical reactions between molecules and their changes and movements. They clarified that the system should allow students to interact with molecules to improve their learning and motivate them to explore the topic. In addition, they stated their need to present the results of chemical interactions. They specified that the system should present chemical compounds in standard molecular models, such as the ball-and-stick molecular model (Turner, 1971), using the CPK colouring schema. CPK is a molecular modelling colouring scheme to distinguish atoms in molecular models developed by chemists Robert Corey, Linus Pauling, and Walter Koltun (Corey & Pauling, 1953). Moreover, the interviewees noted that they require the ability to explore molecules after chemical interactions to help students recognise the chemical interaction steps and understand the chemical interaction process.

5.3.3.2 Macroscopic level

The interviewees reported another vital problem they face in chemistry teaching, the inability to perform chemistry experiments for various reasons, such as the lack of chemicals or time to complete long experiments. In addition, they stated that they do not have time to redo the experiments for absent students and that not all students can perform each experiment individually. To overcome these obstacles, they commented that they only show a video of the experiment when the chemicals or equipment are dangerous. In other cases, students are placed in groups, or the teachers merely perform the experiments themselves. They stated that the available educational simulation systems lack realism in terms of the interaction and interface design, whether for chemicals, equipment, or experiment procedures. They depend on dragging the tools and displaying the results directly without showing the change process that would occur in a real laboratory.

The interviewees stated that they need an educational system that simulates chemistry experiments. In addition, they stated that the system should display all the chemical equipment and substances used in the experiments. Further, the system should allow the user to select one of these objects at a time to perform the current step and present its results as in a real laboratory. The interviewees also indicated their need to examine the final experiment results. They specified that the system should simulate the chemical equipment and substances as real-world representations.

5.3.3.3 General requirements

Participant 2 declared that the system should be reliable in terms of matching the experiment outcomes with real-world experiment results. She stated that most of the available educational systems lack realism in presenting the experiment stages or that they merge some stages. They stated the system should be easy to use and quickly respond to user commands. Moreover, the interviewees indicated the need for instructions and chemical explanations to be displayed clearly for each experiment step. Participant 2 indicated that the system should be usable without training.

5.3.4 Discussion

The interview results reveal that most secondary school teachers face several difficulties in chemistry teaching. One of the most significant difficulties at the microscopic level is explaining molecular structures and chemical compound formation. The teachers use different teaching methods to reduce these difficulties, such as using ready-made images, modelling molecular structures and using board drawings to explain compound formation. However, they verified that these methods are deficient and have many limitations. Concerning the macroscopic level, most teachers face problems in providing students with an opportunity to conduct all the experiments in the laboratory individually and perform them later after an absence from class. These problems are caused by various issues, such as the lack of time or chemicals and risks of hazardous chemicals.

The results confirm that teachers require an educational system presenting the molecular structures of chemical compounds before starting the experiment. In addition, they need a system that exhibits the cleavage and formation of the chemical bonds and all stages of the chemical reaction process. The system should present the final molecular results to help students understand the concepts of chemical reactions.

> Participant 1 stated, '*Presenting the molecules before the reaction, during the reaction, and then after the interaction will explain to the student how chemical bonds break up and rebuild new chemical bonds.'*

Moreover, the findings reveal that the system should present the chemical compounds in a standard molecular model type using the CPK colouring schema.

> Participant 1 reported, '*Yes, but the molecules should display in the ball and stick molecular model, and the colours must match the standard colours.'*

One crucial requirement is that the user must be able to explore molecules after chemical interactions. By applying such a feature in the system, the student can discover molecular structures of the compounds and understand their formations.

In addition, the teachers confirmed their need for an educational system that simulates real chemistry experiments and allows users to interact with chemical equipment and materials.

> Participant 1 stated, '*This would be very helpful.*'

> Participant 2 added, '*This is a good idea.*'

More critical requirements are that the user must be able to perform each step of an experiment, and its outcome should match real laboratory results. With these attributes in the system, the student can perform and better understand each step as in the real laboratory and observe changes to conclude the results.

> Participant 2 stated, '*The student should be able to perform the experiments step by step without integrating the steps, and the system should illustrate the results of each step.*'

Moreover, the design of the chemical substances and laboratory equipment (e.g. glassware and laboratory utensils) should be close to real-world representations. In general, the results indicate that the teachers consider the idea of combining experiment simulation and molecular visualisation concepts useful. The findings illustrate that the educational system should be reliable in terms of matching each process of the chemistry experiment with its expected real experiment result and ensure a quick response to user actions.

> Participant 1 reported, '*It should not take a long time in this process because time is an important factor in the educational process.*'

> Then she added, '*Also, the results should be accurate and correct as described in the books.*'

Participant 2 confirmed that the system is required to provide different experiments and allow the user to select one of them to perform. The system must also support another input device in case the Leap Motion controller is unavailable. One crucial requirement is that the system should be easy to use and should not require training to allow students to use it effectively without teachers' help. Additionally, the user should be able to read the instructions and chemical explanations that illustrate the experiment steps and simplify the chemical symbols and formulas.

Therefore, the interview results confirm that teachers need an educational system with the following requirements:

- The educational system should simulate real chemistry experiments and allow users to interact with chemical equipment and materials.
- The user should be able to do each step of an experiment, and its outcome should match real laboratory results.
- The design of the chemical materials and laboratory equipment should be close to real-world representations.
- The educational system should present the molecular structures of chemical compounds before starting the chemical interaction process.
- It should exhibit the cleavage and formation of the chemical bonds and all phases of the chemical reaction process.
- The educational system should present the chemical compounds in a standard molecular model type using the CPK colouring schema.
- The user should be able to explore molecules after chemical interactions.
- The educational system should be easy to use and not require training.
- It should support another input device in case the Leap Motion controller is unavailable.
- It should present the instructions and chemical explanations that illustrate the experiment steps and the chemical formulas.

5.3.5 User requirements conclusion

Interviewing teachers to determine their issues and needs in chemistry teaching at the secondary level is an essential phase in developing the system to determine the user requirements. This study provides a deep understanding and clarification of the limitations of the available systems and the basic requirements of the proposed educational system, although it relies on a small number of interviewees. In conclusion, the interview results confirm the need for such a chemistry education system combining virtual laboratories and molecular visualisation. Furthermore, this study provides and classifies detailed descriptions of the functional requirements for students. For instance, users should be able to perform chemistry experiments and interact with chemical substances and tools in the same way as in a real laboratory. Further, they should be able to interact with molecules at the microscopic level of the experiment and observe and explore the results of the interactions between molecules. Additionally, this study provides and describes nonfunctional system requirements, such as reliability and usability, for students.

5.4 Proposed Educational System Concepts

Researchers have investigated various techniques to use modern technology to deliver information in teaching, although visual and auditory-based methods are primarily used. The current research aims to develop an educational system for learning chemistry that presents a new and intuitive learning method, integrating the visualisation of molecules and simulated experiments. The user can interact with the system GUI and perform actions via the Leap Motion controller, which is the designated primary input device for the proposed system. Thus, the proposed educational system concepts include gesture-based technology, which is the Leap Motion controller, simulation and molecular visualisation, as illustrated in Figure 5-3. These concepts are integrated to overcome difficulties in teaching chemistry and the shortcomings of the existing systems.

The system includes the simulation of two chemistry experiments intended for secondary school students. These experiments are designed to present a realistic virtual chemistry laboratory and simulate experiments in which students can interact with laboratory tools through the Leap Motion controller. Thus, when the students follow the experiment instructions in the macroscopic view, they can conduct all the steps in the same way they would in a real chemistry laboratory. Moreover, students can view the molecules and chemical bonds with a 3D virtual representation in the microscopic view. They can observe the chemical compounds and their interactions using a specific hand gesture to zoom in. Moreover, if a Leap Motion controller is not available, the system provides an option for students to use a mouse. The fundamental concepts of the proposed system are presented and discussed below. Then, the specifications and description of the system are detailed in the next sections.

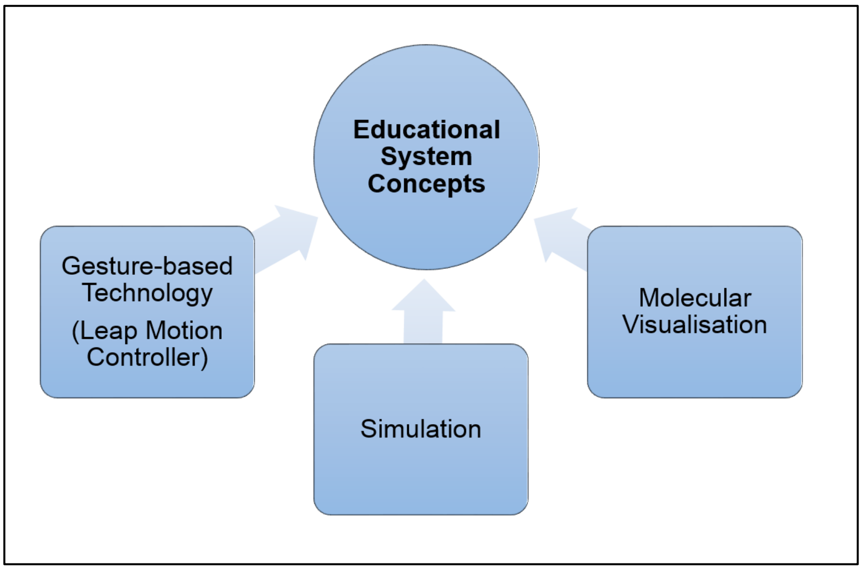


Figure 5-3 Educational system concepts.

5.4.1 Leap Motion controller

A gesture-based interface is a natural and intuitive approach to HCI by effectively detecting and interpreting human gestures. Based on the literature review, gesture-based technology has a significant influence in different fields, especially education. Thus, gesture-based technology could help solve existing system limitations, according to the teachers' interview.

PROPOSED EDUCATIONAL SYSTEM

Many researchers have studied gesture-based devices in education, focusing on specialised topics. Moreover, most of these studies have concentrated on software specifications and have been aimed at professional users and university students. The use of gesture-based technology in educational environments for school students must be investigated in different educational areas.

The Leap Motion controller is a gesture-based device that enables detecting a hand gesture with high accuracy. Previous literature studies have demonstrated the potential of the Leap Motion controller in various applications, such as entertainment, education and health care. However, it is important to continue researching the Leap Motion controller related to chemistry education for school students and support the current studies. Therefore, this work aims to exploit the benefits of this gesture-based device, the Leap Motion controller, in education for school students.

This research uses the Leap Motion controller as one of the primary concepts in developing an educational system for secondary school. The Leap Motion controller is an appealing choice for developing efficient systems targeted at gesture recognition due to its low cost and enhanced efficiency and accuracy. It is a small device that can detect and track two hand objects with 10 fingers and recognise many hand gestures.

These features make it suitable for school use in many classrooms. The controller also improves the interaction experience between students and the proposed educational system with high efficiency and accuracy. Accordingly, it provides a more realistic simulation and allows the user to apply chemistry experiments similar to a real laboratory. As a result, users can perform the experiment steps virtually through hand gestures, such as swiping and movements to grab, move and rotate the laboratory equipment and tools, leading to more realistic simulation at the macroscopic level.

The educational system enhances the manipulation of molecular modelling in an easy, effective and dynamic interaction method. Users can interact with chemical molecules, atoms and bonds virtually through hand gestures, improving the student learning experience and interaction at the microscopic level. Accordingly, the Leap Motion controller provides a virtual simulation and gesture-based interaction with high efficiency and accuracy. Therefore, this system uses the controller to increase user interaction at the macroscopic and microscopic levels and enhance the student learning experience.

5.4.2 Macroscopic and microscopic views

It can be demanding and challenging to teach chemistry because students may find it difficult to find a connection between what can be viewed in a real chemistry laboratory via the naked eye (the macroscopic level) and what is imperceptible to the naked eye (the microscopic level; Gabel et al., 1987; Johnstone, 1993; Petrucci et al., 2010). The implemented system provides two distinct views: the laboratory and molecular levels.

The literature studies have demonstrated that virtual laboratories and simulation have positively influenced chemistry education (Booth et al., 2016; Redel-Macías et al., 2016; Z. Zhang et al., 2017). These methods increase the opportunity for students to perform and understand chemistry experiments procedures in a safer environment. However, many researchers have studied simulation in chemistry education with a focus on the macroscopic level only. Moreover, molecular visualisation has a significant influence on science education. Most molecular visualisation studies have focused on the microscopic level and specialised topics aimed at professional users and university students. Therefore, this research aims to exploit the advantage of combining the macroscopic and microscopic levels by integrating simulation and molecular visualisation. As a result, the research seeks to improve chemistry teaching methods and solve the limitations of the current systems indicated in the teachers' interview.

The system uses simulation techniques to provide a user experience similar to a real chemistry laboratory. It simulates laboratory experiments by granting users the capability to interact with chemical materials, tools and equipment by performing actions with their hands, such as rotating and moving to complete the experiment steps. In addition, chemical models, such as atoms, bonds and molecules, are presented by the system and virtually converted into physicochemical terms to display their appearance in 3D models. As a result, users can manipulate complex molecular structures. Thus, the system can help users comprehend chemical reactions, including how atoms and molecules are rearranged and how their bonds are altered.

5.4.2.1 Simulation

The concept of simulation is extensively used in the field of education. In the previous chapters, literature studies have demonstrated that simulation replicates various dimensions of the actual world in a meaningful manner, enabling learners to engage with the learning process. In addition, simulation offers an effective and efficient learning method.

Previous literature studies have demonstrated that learning through simulation is distinct from listening to a lecture, studying a book, or completing a computer drill, a computer application that presents questions to students and provides them with direct feedback (Ran et al., 2020). In a simulation involving the discovery of scientific concepts, for instance, the input variables are selected, and the experiments are performed by students systematically, recording and observing the outcomes and providing detailed demonstrations of the results. Thus, learning through simulation involves more than the performance of an individual task and is often considered a series of tasks that revolve around creating and using simulations, helping students meet different learning criteria, such as the depth and efficiency of learning content.

Simulation is becoming the most critical tool for enquiry into complicated science-related phenomena. Using this technique within the educational curriculum enables learners to acquire more profound insight into the visual aspects of the objects under study. Therefore, simulation is a fundamental concept in the proposed chemistry educational system for secondary schools in this research. Simulation helps students interact with the systems, components and processes of the educational system. Thus, they gain deeper insight into the underlying behaviour of dynamic objects within a particular field of study. Such experience is generally hard to achieve through traditional learning methods, such as experiential exercises. A scenario-based environment is created through simulation in the proposed educational system, in which students apply the acquired practical skills and knowledge to real-world situations, improving their laboratory skills. Thus, it enables teachers to attain their objectives and reduce the limitations of the current systems.

Computer-based simulation is used in the proposed educational system as a teaching method, specifically as a complement to, or a substitute for, the chemistry laboratory. In the educational system, the application involves simulations of different macroscopic laboratory practices, laboratory tools, and chemical substances. In the macroscopic view, users can perform actions in the system through hand movements and gestures to move and rotate chemistry laboratory equipment, simulating the activities of a real laboratory and allowing users to interact with the chemical tools and substances. The users can observe the nature of reactants, chemical changes, and experiment results, as in a real laboratory.

Based on the overall analysis, simulation plays a significant role in education and has given rise to a new method of learning a concept through computer simulation, specifically in chemistry. The adoption and implementation of such methods would improve the effective learning of new concepts.

5.4.2.2 Molecular visualisation

Various fields, including biology, physics, material science and chemistry, require effective computer programs to develop and visualise molecular and atomic structures. A keystone of advanced molecular simulation is the visual demonstration of molecular structures and their characteristics. According to the literature review, visualisation is essential in guiding how students perceive molecular and atomic structures. Some form of augmentation is required for human perception to observe the world and its manifestations clearly. The studies have indicated that the fundamental objective of molecular visualisation is to gain deeper insight into this complicated world by demonstrating molecular structures, their interactions and characteristics to be intelligible and comprehensible. Visualisation also focuses on reinforcing rational molecular design, such as chemical compounds that possess particular electrical or chemical properties. Thus, visualisation helps students overcome difficulties in understanding and imagining complex and abstract concepts.

Molecular visualisation has become an essential component of advanced studies, specifically in chemistry. Therefore, this research proposes an educational system based on molecular visualisation as a basic concept. In the microscopic view, the system presents a 3D visualisation of molecules, atoms and electrons and allows users to interact with them, enabling users to construct and create complicated molecular structures in a virtual ecosystem. Further, the system enables discovery of spatial formations of molecules, including the bonding attraction of molecules and their interactions. This perspective is expected to enhance the student understanding of how molecules interact in a laboratory experiment performed in the macroscopic view. Molecular visualisation in the educational system assists in demonstrating the perceptive representation of molecules, highlighting particular characteristics and enabling new hypotheses to be developed based on the available data.

Accordingly, molecular visualisation is a significant method in teaching chemistry. The representation of molecular models improves the learning and understanding of different properties of molecules and chemistry concepts. Therefore, the chosen representation of molecular structures in this system is detailed 3D visualisations to improve chemistry learning effectively.

5.5 Proposed Educational System Analysis

This section presents the key elements of the proposed educational system analysis, starting with describing the user characteristics. Then, this section illustrates the functional and nonfunctional requirements and identifies the constraints on the system services or functions and how the system should behave under certain conditions. These requirements were derived from the previous research in Chapters 2 and 3 and the user requirements interview in Section 5.3.

5.5.1 User characteristics

The planned system users are secondary school students. Users must have prior knowledge and skills in the basics of chemistry and be familiar with chemistry equipment and performing experiments in a laboratory. They must also have experience with computers and their applications. Users with greater experience in simulations, e-learning systems and virtual environments are expected to find it easier to use the system.

5.5.2 System requirements

This section presents the system requirements to determine the provided system services and constraints under which it operates. These requirements are defined based on user needs and a review of existing educational systems. These requirements are classified into functional and non-functional requirements.

5.5.2.1 Functional requirements

- In the macroscopic view, the user should be able to perform a chemistry experiment, complete the steps and determine the experiment results, as in a real laboratory.
- The users should be able to transform from the macroscopic view to the microscopic view of the experiment.
- In the microscopic view, the user should be able to interact with molecules to begin the reactions and find the interaction procedures.
- The user should also be able to determine and explore the results of interactions between molecules.
- Finally, the user should be able to locate instructions and chemical equations and explanations that illustrate the experiment steps.

5.5.2.2 Nonfunctional requirements

1. **Reliability**

- The system should be reliable in terms of matching each experiment step with its results (i.e. what would be expected to happen in the experiment).
- The system should also display the chemical equipment and substances as real-world representations.

- The system should present chemical compounds in standard types of molecular models, such as the ball-and-stick model or space-filling model, using the CPK colouring schema.

2. **Usability**

- The system should be simple and easy to use, requiring less than two hours of training.
- The user should be able to move easily from the macroscopic to the microscopic view with a single action.

3. **Flexibility**

- The system should support multiple input devices, the Leap Motion controller and the mouse.

5.6 System Design

This system design section presents information to implement the educational system designed for performing chemistry experiments through simulation and molecular visualisation. This section provides the architectural design and design rationale.

5.6.1 System architecture

Figure 5-4 illustrates the system architecture from a high-level perspective. The system is implemented using the following distinct components:

a. **Leap Motion API:** The interface for handling the connection between the computer and input device and generating input events.

b. **Educational System:** The educational system provides a simple laboratory-like environment enabling the operator to represent experiment events that are likely to occur in real-world performance.

c. **Educational System Interface:** The system interface is used for building and managing events and displaying updates.

d. **Unity 3D Framework:** This framework executes the updates and visualises them for the user.

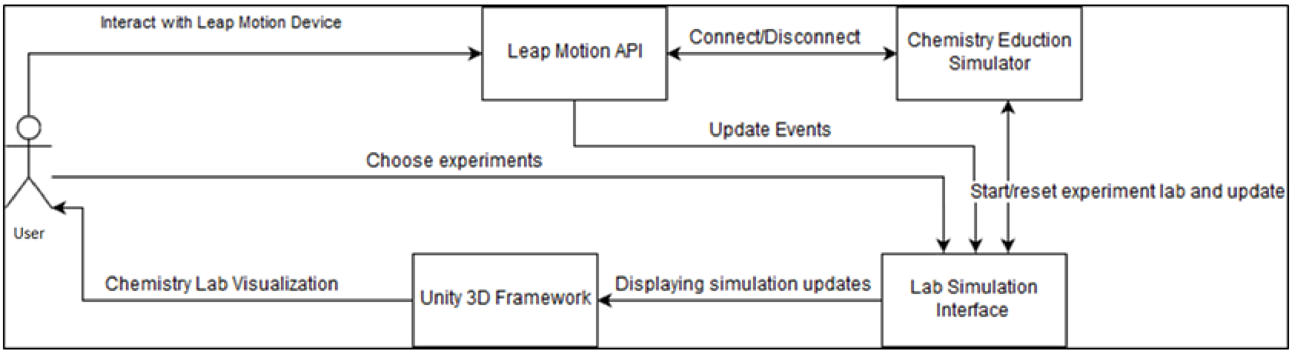


Figure 5-4 System architecture diagram.

5.7 System Implementation

The system is designed and developed using Unity 3D as its main engine. Although C# was used as the primary programming language for system implementation, the system supports several programming languages. It was designed to present a realistic chemistry laboratory using 3D virtual representations of tools and equipment and simulate chemistry experiments in which molecules, atoms and chemical bonds can be viewed in 3D representations (Figure 5-5).

Furthermore, the Leap Motion module is integrated with the system to enable communication with the Leap Motion controller. The system uses the Leap Motion controller as the primary input device, which is implemented using the Leap Motion controller API. The controller allows for performing various system tasks, including moving objects and completing experiment steps.

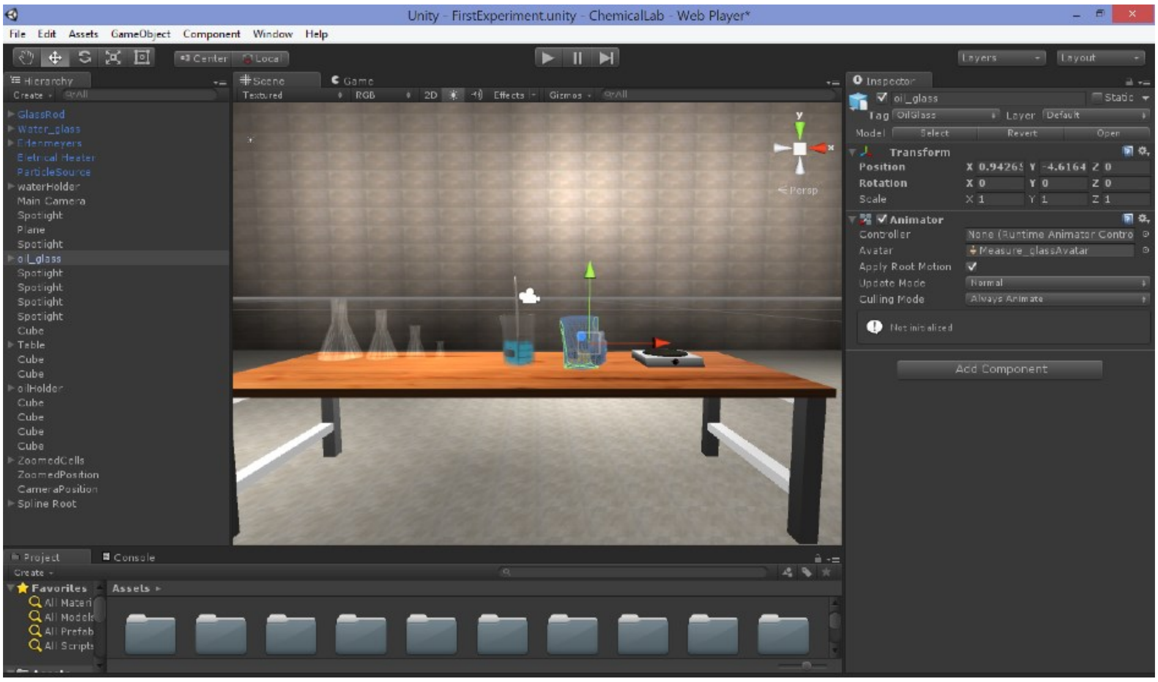


Figure 5-5 Interface development using Unity 3D.

5.8 System Description

The system presents two different experiments, which can teach chemistry to secondary school students. The two experiments were referenced from the secondary textbooks in Saudi Arabia, which were edited and translated from *Chemistry: Matter and Change* (Buthelezi et al., 2008). These experiments are selected in collaboration with a secondary school chemistry teacher. They are designed to integrate the macroscopic and microscopic levels. The macroscopic view of each experiment presents the experiment as it would occur in a chemistry laboratory, and the microscopic view presents the experiment from the molecular perspective.

Input devices: The system supports the Leap Motion controller as the primary input device to provide gesture-based interaction and simulate hand movements. It also supports the mouse as an alternative input device if the Leap Motion controller is unavailable. Supporting two input devices increases the system flexibility. Figure 5-6 depicts the system as used by a student on a computer.

Macroscopic view: At the macroscopic view, the user can interact with the system through the selected input device in each experiment and carry out the steps of an experiment in the same way as in a laboratory. The user can grab, move and rotate chemical substances, tools and glassware using physical movements to conduct the experiment steps similar to those in a real laboratory. Thus, if the Leap Motion controller is selected, the user can carry out all procedures of the experiment and follow the experiment instructions using hand gestures. This process enhances the laboratory simulation and improves the learning experience. If the mouse is selected as the input device, the user can carry out all procedures using the drag-and-drop functionality.

Experiment instructions and some additional explanations are displayed on the top left corner of the scene in the selected language, English or Arabic. These features increase the system effectiveness and improve its self-learning capability.

Since the proposed educational system is designed based on a scenario-based method, it provides some freedom to the user to act in the virtual laboratory. The user has to perform the current step of the experiment and can fail in applying it, such as pouring the liquid outside the beaker. However, the user has to repeat it and will not move to the next step until the current step is performed correctly. This applies to all steps of the two experiments.

Thus, as users perform each experiment step, the scene changes based on the expected response, as in a real-world laboratory. The appearance and colour of the chemical substances in each experiment step are displayed as they should appear in a real-world laboratory. These specifications improve the simulation efficiency and enhance the student learning experience.

When the user has completed all experiment steps, the final results and changes in the chemical reactions can be observed. Thus, it enhances the ability of the user to acquire knowledge and practical skills as in a real-world laboratory, in addition to other benefits provided by the system.

Next, the user can zoom in to view the chemical compounds and examine the final outcome. The molecules and atoms can then be manipulated through the 3D representations, and the chemical bonds can be observed in the virtual microscopic view.

Microscopic view: In the microscopic view, atoms and molecules are displayed by the system in a graphical representation using the CPK colouring schema. In chemistry, the molecules and atoms are distinguished through this widely used colouring schema (Jmol, n.d.). In this view, the user can examine and interact with electrical forces and the properties of molecules and atoms presented in a 3D virtual representation. The user can move and rotate the atoms and molecules using hand gestures, enhancing the interaction experience with the system interface and the simulation efficiency. The user can also use drag-and-drop actions to move and rotate the atoms, molecules, and bonds using the mouse.

After users have interacted with atoms and molecules, they can observe molecule interactions and movements in the experiment. They can observe the changes, how bonds break and how new bonds are constructed between atoms to form the resulting chemical compound of the interaction. Instructions, chemical symbols of compounds, and chemical equations are displayed to the user on the screen at each step. In the microscopic view, different gestures can rotate the 3D molecular models representing chemical compounds.

Using these gestures, the user can explore chemical bonds and the molecular structure of the resulting chemical molecules. The system, in this view, allows the user to visualise and interact with abstract concepts to overcome difficulties in understanding complex chemical reactions. Accordingly, this view enables the proposed system to enhance the student learning outcomes by visualising molecular concepts.

Start page: The start page of the system has a menu-based interface allowing the user to specify the application options and features, select one of the two chemistry experiments, implement it and study it through the system (Figure 5-7). The user can choose between two input device options, the mouse or Leap Motion controller, and between two application language options, English or Arabic. Depending on the user's choice, the system displays instructions and information on the chemistry experiments in the appropriate language. The main menu is illustrated in Figure 5-8, and the options submenu is in Figure 5-9. In addition, the user can read more about the system in the about window, illustrated in Figure 5-10, which summarises the system aims and features. Overall, the system interface is designed to be simple and easy to use without substantial training, making the proposed system user-friendly.

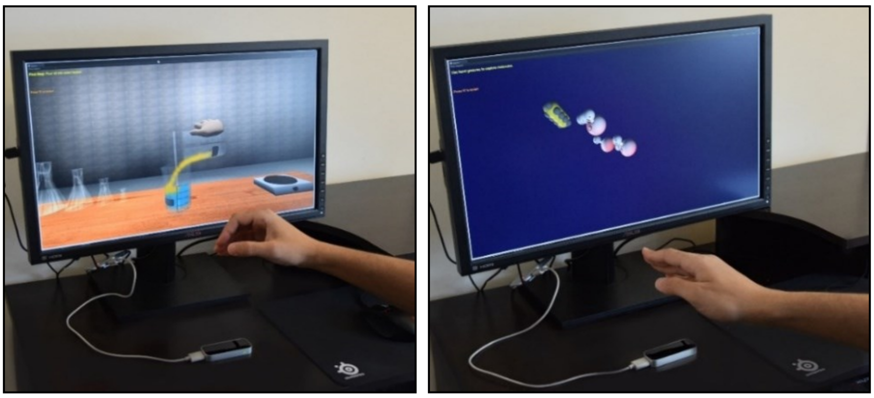


Figure 5-6 A student using the system.

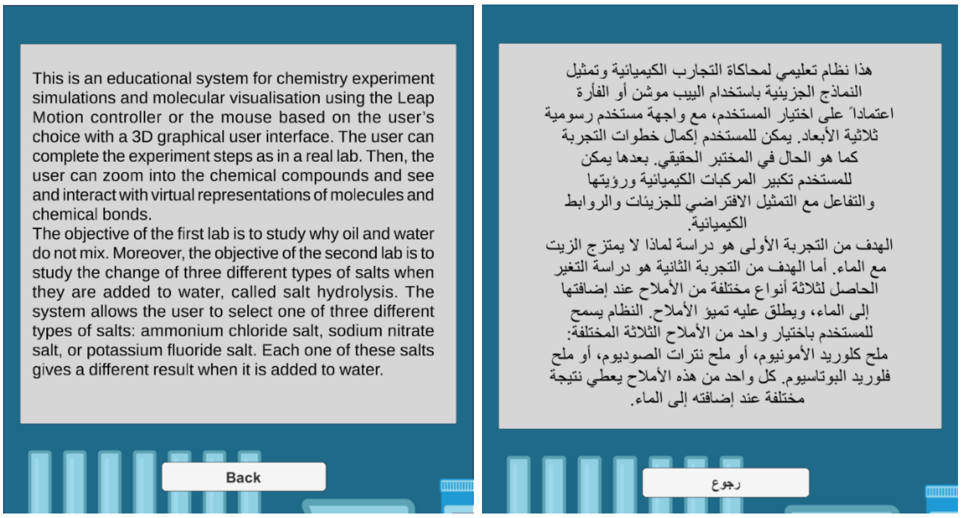
Figure 5-7 Start page of the system.

(a) (b)

Figure 5-8 Main menu of the system in (a) English and (b) Arabic.

(a) (b)

Figure 5-9 Options submenu of the system in (a) English and (b) Arabic.



(a) (b)

Figure 5-10 About window in (a) English and (b) Arabic.

5.8.1 First chemistry experiment

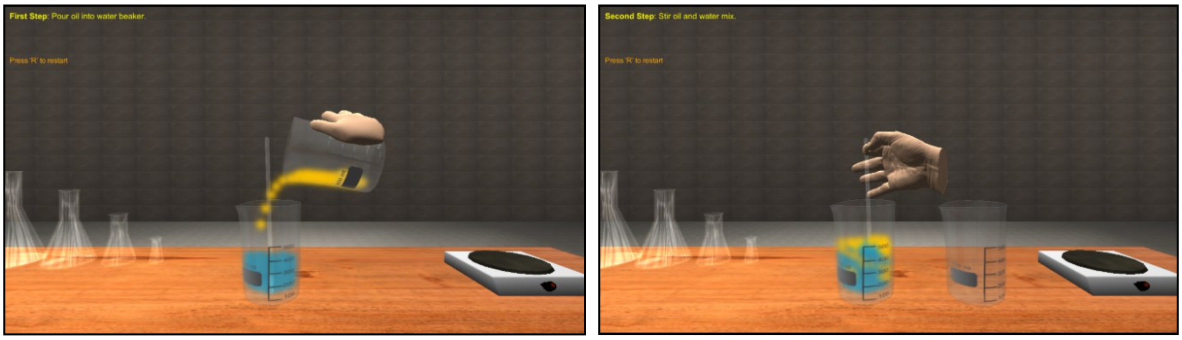
This experiment aims to investigate the inability to mix water and oil. It presents the required tools and materials for conducting the experiment and displays the molecular structures in the macroscopic and microscopic views.

Macroscopic view: The experiment begins at the macroscopic view, with oil and water presented in two beakers. The user pours the oil into the water and can perform the step either correctly or incorrectly. However, the user has to perform the current step correctly to move to the next one. If the oil is poured outside the water beaker, the user has to redo the step until it is performed correctly. Then, the user mixes the beaker with a glass rod virtually through interaction with the system via the input device. The user completes this step with hand gestures using the Leap Motion controller or with the drag-and-drop actions using the mouse, simulating the actions of pouring the oil into a beaker and mixing the chemical mixture using a rod in a real laboratory. After pouring the oil into the water and mixing it, the oil droplets are spread throughout the water, as illustrated in Figure 5-11(a, b). Later, the droplets of oil rise to the surface and can be observed above the water, similar to what can be observed in a laboratory, as oil is less dense than water (Buthelezi et al., 2008; R. Chang, 2010).

Microscopic view: When users have completed all the experiment steps, they discover the chemical mixture by transforming it into the microscopic view. The user taps the screen remotely via the Leap Motion controller or clicks it via the mouse to zoom in on the chemical mixture and move to the microscopic view. Here, the user can gain an understanding of the rationale of the chemical process and comprehend the concepts of the experiment.

Water (H_2O) is classified as a polar molecule because hydrogen has a positive charge and oxygen has a negative charge. In contrast, oil is classified as a nonpolar molecule, as it is composed of noncharged hydrocarbon sequences. The user takes the oil molecule and moves it to mix it with the water molecules virtually via interaction with the system through the selected input device and the 3D virtual representation of the molecules. The user conducts the molecular interaction steps using hand gestures, such as grabbing, translating, and rotating, using the Leap Motion controller or using drag-and-drop actions with the mouse. Thus, when the oil molecules, which are noncharged, are mixed with the charged water molecules, the two substances do not mix due to the lack of force fields between them (Buthelezi et al., 2008; R. Chang, 2010).

The screenshot in Figure 5-12 illustrates how, after the user has added the oil molecule to the water molecules, the system demonstrates how the molecules move and interact. Eventually, two separate layers are formed. All the steps are shown for the user with chemical explanations, and the user also can use gestures to explore the scene and observe the molecule structures, such as swiping and circling gestures. Therefore, the microscopic view of the experiment allows the system to increase the student understanding of the experiment's molecular concepts.



(a) (b)

Figure 5-11 Screenshots of the first experiment while the system was being used in the macroscopic view: (a) pouring oil into the water and (b) stirring the water and oil mix.

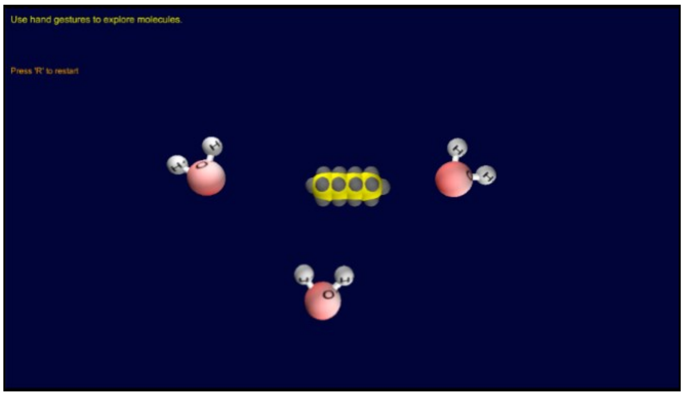


Figure 5-12 Microscopic view of the first experiment.

5.8.2 Second chemistry experiment

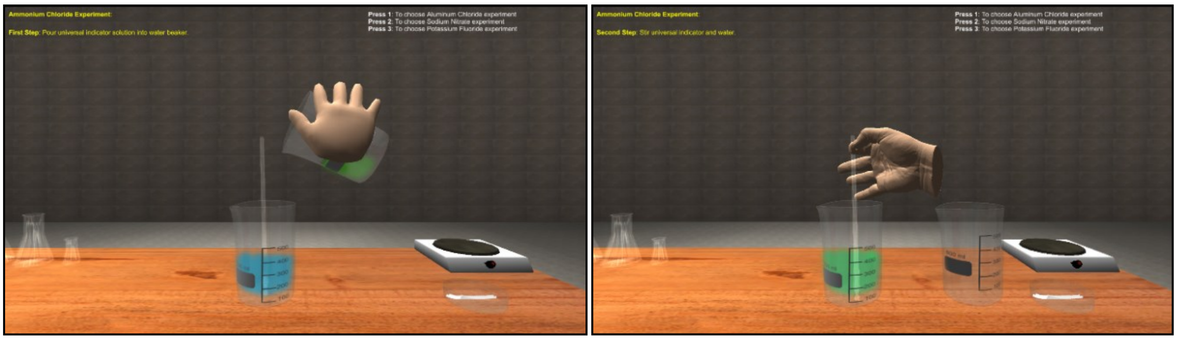
This experiment studies how different types of salt react and transform after mixing them with water. After starting the experiment, the user can choose one of three types of salt: sodium nitrate salt, potassium fluoride salt or ammonium chloride salt. A different result can be observed when each of these salts is mixed with water.

The experiment begins in the macroscopic view, in which the user can complete the experiment steps through interaction with the system via the input device using hand gestures with the Leap Motion controller or drag-and-drop actions with the mouse. In each step, the user has to try to perform it correctly to move to the next step. Then, the user can examine the resulting solution as it changes, as in a real-world laboratory.

Next, a better understanding of the experiment, including the chemical reactions, was achieved by allowing the user to transform to the microscopic view where the molecules, atoms and bonds between them can be viewed. The user can also use hand gestures to interact with molecules and observe the chemical reaction and molecule structures. Then, the user can explore and observe the final results by rotating around the 3D molecules using swiping and circling gestures with the Leap Motion controller or drag-and-drop actions with the mouse.

1) Ammonium chloride salt: The user adds the universal indicator liquid to the water beaker in the macroscopic view, pouring it virtually to simulate the natural actions of pouring liquid into a real beaker using hand gestures, such as grabbing, translating, and rotating. Then, the user stirs the chemical mixture using the glass rod virtually through hand gestures to simulate the actions of stirring using a real rod. The mix is stirred using drag-and-drop actions with the mouse.

After the user stirs the mixture via interaction with the input device, the water colour changes to green, as illustrated in Figures 5-13(a) and 5-10(b). The user takes the ammonium chloride salt (NH_4Cl), adds it to the water beaker, and blends it with a glass rod by virtually moving the chemical glassware using physical movements as in a real laboratory (Figure 5-14). The user can also use drag-and-drop actions to conduct the experiment steps using the mouse. The water and salt mix causes the colour to change to yellow, implying an acid is formed (Buthelezi et al., 2008; R. Chang, 2010; Petrucci et al., 2010).



(a) (b)

Figure 5-13 Screenshots of the second experiment in the macroscopic view: (a) pouring the universal solution into the water beaker and (b) the colour change of the water.

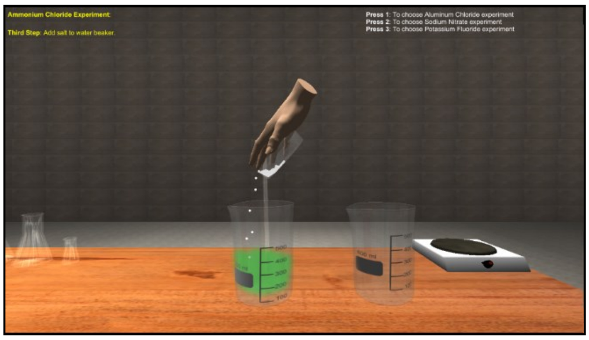


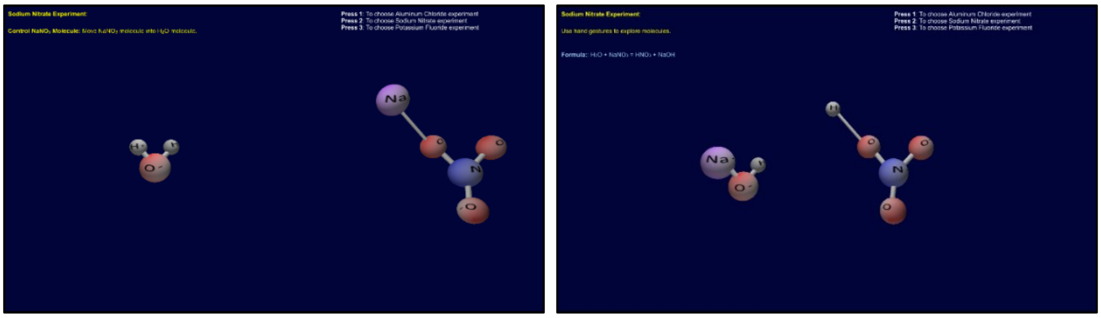
Figure 5-14 Screenshot of using the system when adding the ammonium chloride salt to the universal solution and water mixture beaker.

Next, the reaction is explained from a microscopic perspective. The user interacts with the microscopic view through the selected input device and the 3D virtual representation of molecules. The user moves the ammonium chloride salt molecule virtually to mix it with the water molecule using hand gestures, which are recognised using the Leap Motion controller. The molecules can be moved using drag-and-drop actions when the mouse is selected as an input device. Accordingly, the water molecule is ionised into hydrogen ions (H^+) and hydroxide ions (OH^-). The ammonium chloride salt dissolves in water into chloride ions (Cl^-) and ammonium ions (NH_4^+). The hydroxide ions react with the ammonium ions to form ammonium hydroxide, whereas hydrochloric acid is formed when hydrogen ions react with chloride ions. In this scenario, a relative abundance of hydrogen ions is observed in the final result, producing an acidic solution (Buthelezi et al., 2008; R. Chang, 2010; Petrucci et al., 2010). Thus, the user can realise the cause of changing the solution colour to yellow. The user can also understand the rationale for the chemical reactions between the ammonium chloride molecule and water molecule and the concepts of the experiment. Figure 5-15 illustrates screenshots of the system when the user adds ammonium chloride molecules to the water molecule, revealing how the final result is formed when the reaction occurs.

2) Sodium nitrate salt: The user begins by virtually adding the universal indicator liquid to the water and mixing it with a glass rod through hand gestures, simulating physical movements, as in a real laboratory using interaction with the Leap Motion controller. Afterwards, the colour of the water changes to green. The user adds sodium nitrate salt ($NaNO_3$) to the beaker and mixes it through interaction with the Leap Motion controller. When the user adds sodium nitrate salt, the colour does not change because the resulting mixture forms a neutral solution.

A sodium nitrate molecule and water molecule are presented in 3D virtual representation in the microscopic view in Figure 5-16(a). Then, the user moves the sodium nitrate molecule virtually to mix it with the water molecule. This step is performed using hand gestures recognised by the Leap Motion controller or drag-and-drop actions using the mouse. When the water molecule is added to the sodium nitrate molecule through interaction with the system via the selected input device, the water molecule ionises into a hydrogen ion (H^+) and hydroxide ion (OH^-). The sodium nitrate molecule dissolves in the water, forming a nitrate ion (NO_3^-) and sodium ion (Na^+). A reaction occurs between the hydroxide ion and sodium ion, forming sodium hydroxide, a strong base. Simultaneously, another reaction occurs between the hydrogen ion and nitrate ion, forming nitric acid, a strong acid (Buthelezi et al., 2008; R. Chang, 2010; Petrucci et al., 2010). In this scenario, the final result is a neutral solution in which the colour remains constant, displayed in Figure 5-16(b). Thus, the molecule 3D representation and molecular interaction scenario allow the user to observe and understand chemical reactions between the sodium nitrate and water molecules, including molecular concepts.

Figure 5-15 Screenshots of the final chemical reaction between water and ammonium chloride molecules in the microscopic view.



(a) (b)

Figure 5-16 (a) Three-dimensional visualisation of water and sodium nitrate molecules before the chemical reaction; (b) the final form of the molecules after the chemical reaction.

3) Potassium fluoride salt: The user interacts with the system using the input device and pours the universal indicator liquid beaker into the water beaker, mixing them using the glass rod. The user conducts pouring and mixing actions virtually using hand gestures recognised by the Leap Motion controller, simulating real-world actions in a laboratory.

Afterwards, the potassium fluoride salt is virtually added to the beaker containing the mixture through hand movements and interaction with chemical glassware using the Leap Motion controller. Further, the user can conduct the steps using drag-and-drop actions with the mouse. The colour of the water changes to blue after mixing the salt, implying a base is formed to simulate the expected results in a real laboratory.

Next, the user can zoom in and examine the resulting compound by transforming from the macroscopic to the microscopic view. Depending on the type of input device, the user transforms to the microscopic view either by tapping the screen remotely when using the Leap Motion controller or by clicking the resulting compound with the mouse, as illustrated in Figure 5-17. Screenshots of the system displaying the 3D virtual representations of potassium fluoride and water molecules are presented in Figure 5-18(a).

Then, the user uses hand gestures to move the potassium fluoride molecule and add it to the water molecule virtually. The system simulates the molecule movements and chemical reactions. The reaction causes the water molecule to ionise into a hydrogen ion (H^+) and hydroxide ion (OH^-). Moreover, fluoride ions (F^-) and a potassium ion (K^+) are formed when the potassium fluoride molecule dissolves in water. Potassium hydroxide is formed when a reaction occurs between the hydroxide ion and potassium ion, while hydrofluoric acid is formed from the reaction between the fluoride ion and the hydrogen ion, as presented in Figure 5-18(b).

In this scenario, a relative abundance of hydroxide ions can be observed as the final result, providing a base solution; thus, the colour of the mixture changes to blue (Buthelezi et al., 2008; R. Chang, 2010; Petrucci et al., 2010). The user also can explore the final results and rotate the molecule structures using hand gestures. Users can observe the chemical reaction process and understand its concepts and components, which can be useful in overcoming difficulties in chemistry learning.

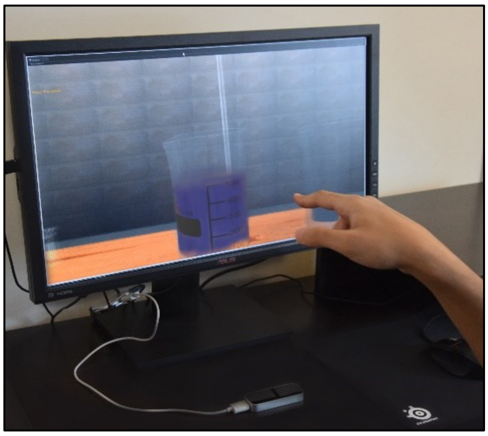
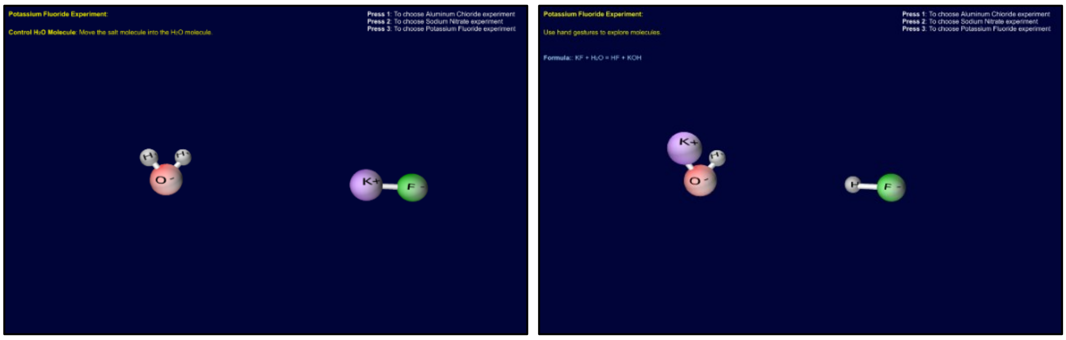


Figure 5-17 A student remotely uses the system and performing a tap action on the screen, which is recognised by the Leap Motion controller and used by the system to transform to the microscopic view.



(a) (b)

Figure 5-18 (a) Three-dimensional visualisation of the potassium fluoride and water molecules before the chemical reaction and (b) the final form of the molecules after the chemical reaction.

5.9 Chapter Summary

This chapter introduces and analyses a chemistry educational system that merges a simulated experiment with molecular representation using the Leap Motion controller. The interview with the teachers identified the teacher and student requirements as system users. Then, the concepts and methodologies of this system were reviewed in detail. The Leap Motion controller and two contrasting macroscopic and microscopic views provided by the proposed system via simulation of a chemistry laboratory and molecular visualisation of the molecular level were described. The development process of the system was discussed in detail in this chapter with the system analysis and requirements, including functional and nonfunctional requirements. Moreover, the system design was presented along with the involved system architecture, design diagram and implementation.

Two chemistry experiments were included in the system, which can be used for teaching chemistry in secondary schools. The specifications of these two experiments and the system interface, including the macroscopic and microscopic views, were elaborated on in this chapter. In the macroscopic view, the laboratory simulation and gesture-based interaction allow users to perform the experiment procedures and acquire practical skills and knowledge. This view was designed to improve experiment simulation and enhance the learning experience. Moreover, in the microscopic view, the interaction with 3D molecular compounds through the gesture-based interface allows the user to observe the chemical reaction processes and understand the concepts. This view was designed to improve the student comprehension of chemistry concepts and overcome learning difficulties.

Chapter 6. USER TESTING

6.1 Introduction

The proposed educational system is designed for teaching chemistry in secondary schools by integrating the visualisation of molecules and simulation of experiments. However, it is challenging to assess the system to ensure high-quality results in such an environment. Therefore, this research applies three phases of research methods, as discussed in Chapter 4. This chapter presents and discusses the first and second phases to test the proposed educational system with different users: a teacher interview study and usability testing.

The system must be tested and discussed with teachers who have experience in the same field to ensure its educational effectiveness and that it meets all requirements to examine its strengths and deficiencies and evaluate the results of using it with school students. Therefore, several teachers were interviewed after testing the system, and their assessments of the system were studied. Moreover, usability testing was conducted to evaluate the system interface, usability, architecture and information flow, considering the user requirements discussed in Chapters 5. The methodologies of the interview study and system usability testing were discussed in Chapter 4 above. The interview study and system usability testing procedures and results have been published in (Aldosari & Marocco, 2016; 2017).

6.2 Interview Study

The first phase (an interview study) of studying and testing the educational system allowed teachers to use and assess the system. The study results were analysed to better understand the effects of this system on chemistry learning. Individual interviews were conducted with five teachers with experience teaching chemistry in secondary schools to investigate the users' experience with the educational system. They tested the system by completing all the experiment tasks using the mouse and the main input device, the Leap Motion controller. The responses from the teachers were evaluated using qualitative content analysis. Generally, the teachers gave positive feedback about the concept of merging the macroscopic view of a chemistry laboratory with the microscopic view at the molecular level and about using the gesture-based device.

6.2.1 Methodology

The methodologies of the interview study were discussed in Chapter 4. The interviews were conducted in January 2016. The teachers tested the proposed educational system under the supervision of the researcher. Before they began testing the system, they were given a simple explanation. This explanation included descriptions of what the system is, how it works, the provided experiments, how to use it, and how to use the Leap Motion controller. Then, the teachers first tested the system with the Leap Motion controller before testing it with the mouse. Furthermore, there was no time limit to avoid errors due to time pressure.

A framework was designed in advance of the interviews to focus on specific subjects, including the difficulties facing chemistry teachers and the teachers' prior experience and knowledge of using educational systems. Furthermore, the framework covers their experiences with the proposed educational system in terms of usability, interface design, interactivity via the input hardware and whether information can be learnt through the proposed system. After they tested the proposed system using two input devices, the Leap Motion controller and mouse, the teachers were interviewed and finished all the steps needed to conduct the chemistry experiments. The interview questions are available in Appendix C, and the interview transcripts are in Appendix D.

6.2.1.1 Participants

Each interviewee's basic information is listed in Table 6-1, including the gender, age, years of teaching experience, current educational level, computer usage frequency and computer skill rating. The participants all held a bachelor's degree, and their teaching experience varied between 5 and 18 years, with an overall average of 10.2 years and good-to-excellent computer skills.

Interviewees No.	Gender	Age	Current level of education	Years of teaching experience	Computer usage frequency	Computer skills rating
1	Female	Under 30 years old	Bachelor's degree	5	Often	Excellent
2	Female	30-40 years old	Bachelor's degree	6	Always	Excellent
3	Female	30-40 years old	Bachelor's degree	12	Always	Good
4	Female	40-50 years old	Bachelor's degree	18	Moderately	Moderate
5	Female	30-40 years old	Bachelor's degree	10	Moderately	Good

Table 6-1 Interviewee profiles.

6.2.1.2 Data analysis process

The data analysis method is discussed in Chapter 4. During the analysis process, the following themes were identified:

- teachers' previous experience using educational systems, including e-learning and simulation systems; problems facing teachers and
- their experiences using the proposed educational system, including its general characteristics, input devices specifications, usability features and interface design;
- the ability to acquire knowledge after using the system; and

- their final opinions of the system.

These themes and the relationships between them are depicted in Figure 6-1. Figure 6-2 exhibits the interrelationships for the themes of the interview study, and Figure 6-3 presents an example of the data analysis approach of the interview study.

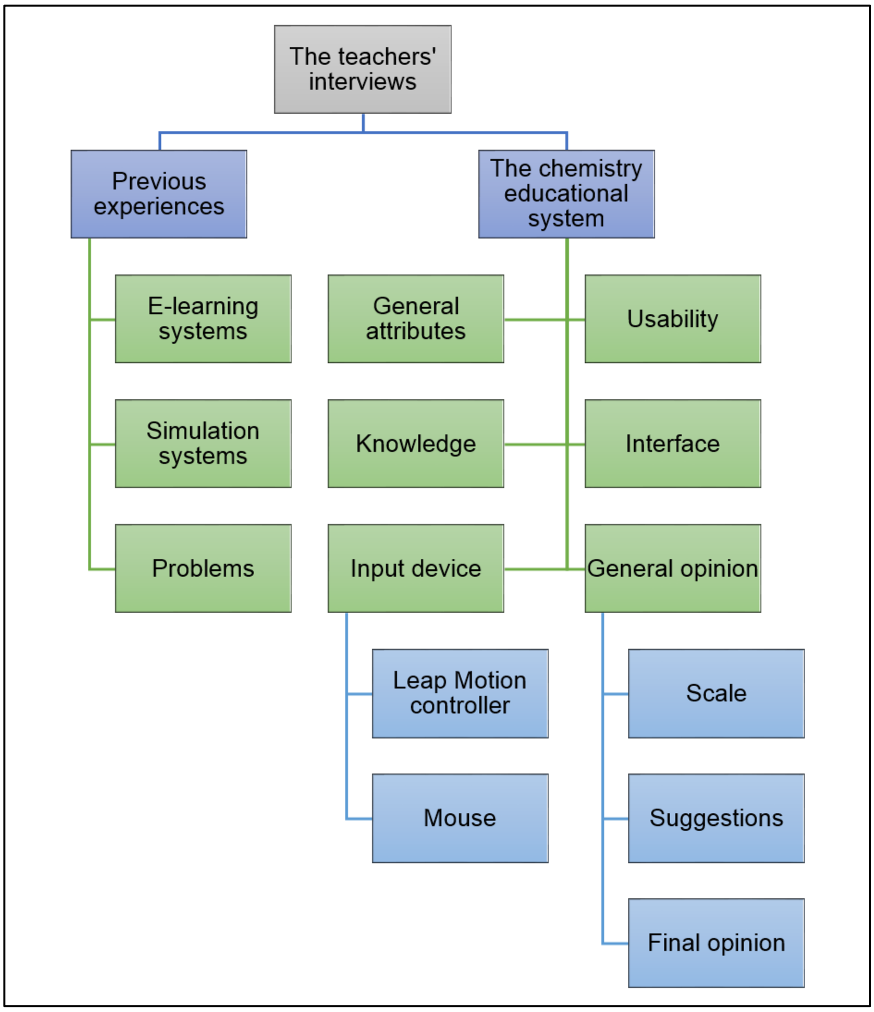


Figure 6-1 Themes of the interviews and relationships between them.

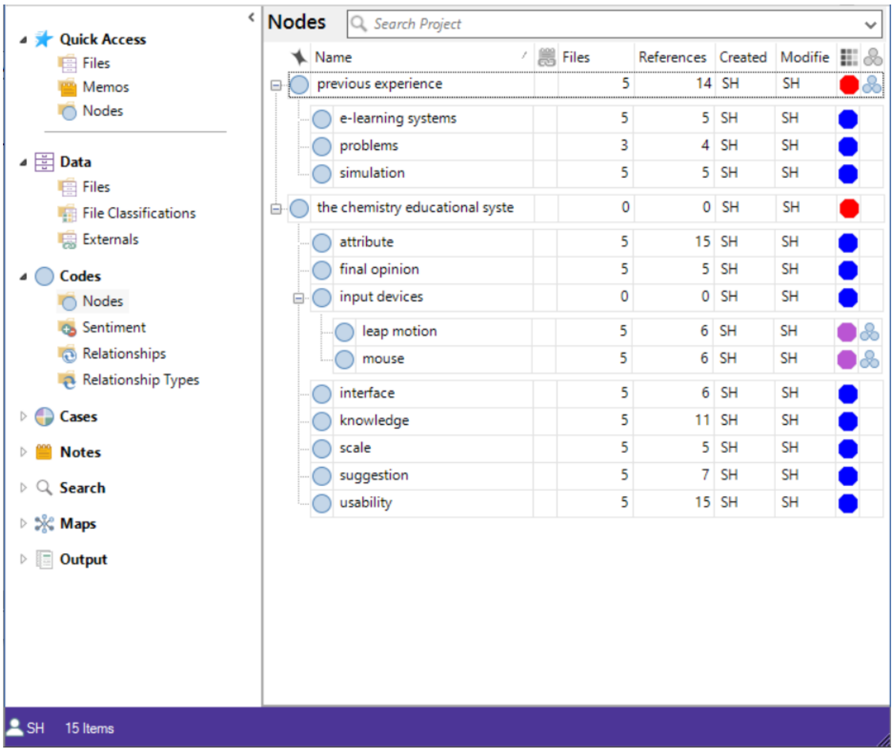


Figure 6-2 Interrelationships for the themes of the interview study from NVivo.

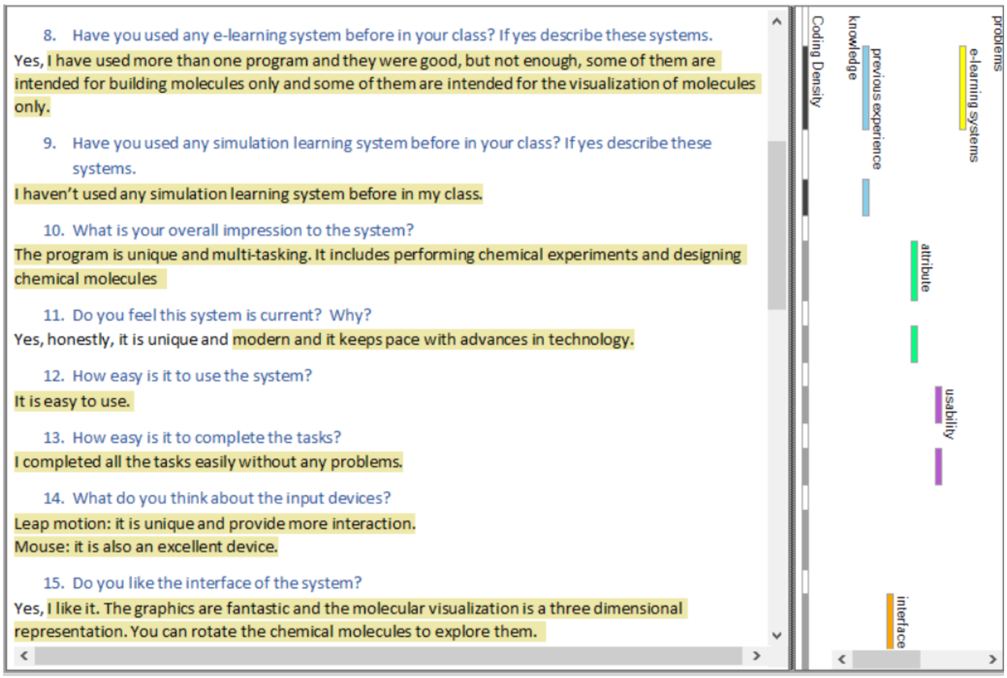


Figure 6-3 Example of how to approach data analysis of the interview study.

6.2.2 Results

The results of analysing the study data are presented in this section. They include teachers' previous experience using educational e-learning and simulation systems, the problems facing them and their experiences using the proposed educational system.

6.2.2.1 Previous experiences

All the interviewees stated that they had previously used e-learning systems for teaching chemistry, including web-based course management applications, interactive whiteboards, video-sharing websites and tools for solving chemical equations. Most had used software intended only to visualise molecules, whereas Interviewee 1 had used software for building molecules. Three participants had not used any simulation systems, and two participants had used only a few educational systems.

Three participants had encountered a range of problems in conducting laboratory experiments due to a lack of materials, the risk that some experiments might cause to students and the increasing class sizes. The dependency on theoretical learning alone is caused by issues, such as the need for exam preparation and repeating the experiments. A major obstacle facing students in class is understanding the components of molecules.

6.2.2.2 Experience using the presented system

All five participants stated that they enjoyed the educational system and defined it as an exceptional and modern system. Three participants liked how the system includes chemistry experiments that can be performed in a virtual laboratory and the design of the chemical molecules. Two participants liked the representation of molecular interactions in which the chemical bonds break and recombine after the interaction. All participants indicated that they liked the provision of a realistic simulation. Interviewee 1 particularly appreciated the accuracy of the experiment steps, and Interviewee 3 liked the instructions for each step being shown as text on the screen.

a. Usability features

All participants stated that the system was easy to use. Users could complete all tasks easily without assistance. Interviewee 4 stated that no practice was needed to use the system, whereas Interviewee 3 indicated that practice would be needed for students to use the system. Interviewee 5 liked the clear and descriptive directions, whereas Interviewee 4 stated that a few students might need a user guide.

Regarding acquiring knowledge from the system, all participants reported that the system provides information that meets user needs. Most indicated that the system could frequently avoid the need for theoretical clarification, but one participant, Interviewee 4, felt that the system could not dispense with this need. All participants stated that the educational system would help students comprehend the main ideas behind the experiments and their concepts, with the benefits detailed below.

First, three participants felt that students would be able to conduct chemistry experiments using this system. The system would be beneficial when materials or tools are inaccessible or when certain materials pose a risk to students. A specific feature of this system is that the students can repeat the experiments as often as they desire to help them prepare for school exams. Furthermore, four participants indicated that when the students interact with the molecules and chemical compounds in the microscopic view, they can discover precisely how molecules and atoms interact and form the final result. Interviewee 3 stated that the information was clearly and comprehensibly provided, and the system would facilitate explaining experiments in the classroom.

b. Interface and input device specifications

All five participants stated that they liked the proposed system's interface and graphic design. Three participants appreciated the 3D molecular visualisation, which they found more useful than a board drawing, and the ability to rotate chemical molecules to explore them. Interviewee 2 commented on how the colours of the chemical compounds and materials were close to reality, and Interviewee 5 liked how the system presents a virtual laboratory equipped with all the materials and tools required to complete the experiment.

All participants described the Leap Motion controller as an outstanding and exceptional device. They found it superior overall to the mouse and felt it delivered further interactivity and engagement.

> Interviewee 2 stated about the Leap Motion controller, '*It is better because the student can practise as if she is in a real lab.*'
>
> Interviewee 1 reported about it, '*It is unique and provides more interaction.*'

Three participants declared that the Leap Motion controller delivers a better simulation of reality, as the hand movements almost match the users' hand movements. The participants described the mouse as a fine and adequate device, although Interviewee 1 indicated that it offers less interactivity than the Leap Motion controller. Nevertheless, the mouse is a popular device that can be found anywhere and offers faster interaction and ease of use.

c. Final opinions

The participants were asked, '*How much do you think the system can help students to understand the concepts of the experiments on a scale of 1 to 5 (where 1 stands for not at all and 5 very much)?*' Four out of them rated the proposed system as 5 out of 5, with one rating it as 4 out of 5. All participants reported that they would like to use the system in their classes. Interviewee 3 stated that it would help explain experiments, and Interviewee 5 viewed it as a valuable tool for helping students grasp the concepts and ideas of experiments. The participants suggested some adjustments to enhance the system, such as offering instructions for experiment tasks and system menus in Arabic and including sound effects. In addition, they recommended adding several chemistry experiments and addressing complex subjects.

6.2.3 Discussion

The interview results demonstrate that all participants had prior knowledge and experience using e-learning systems for teaching chemistry. They used websites to communicate with students, submit assignments, create quizzes, and grade them.

> Interviewee 3 stated, '*I have used Edmodo. It is a website that offers many tools to help you communicate with the students, submit assignments, create quizzes and grade them.*'

Moreover, they used different e-learning systems for teaching chemistry, and they mentioned that existing educational systems can display molecule representations and provide experiment videos and chemical calculators.

> Interviewee 2 reported, '*I have used different programs. They display molecule visualisations of chemical compounds or play videos of the steps of the experiments.*'

However, the findings reveal that existing educational applications, such as e-learning systems, suffer from various shortcomings, such as a lack of interaction or ineffective simulations. They described the available simulation systems and their limitations and clarified that they either perform experiments steps automatically or by simply clicking buttons without any real interaction by the user.

> Interviewee 2 stated, '*I have used one program. It was displaying a list of experiment steps. When you press on any step, it shows a flash video and automatically executes this step.*'

> Interviewee 3 said, '*I used a flash video to explain the chemistry experiments by selecting the name of a specific experiment, and then this experiment is executed automatically.*'

In addition, the results indicate that it can be complex and time-consuming to have the experiments conducted by each student in a real laboratory. This problem was one of the main challenges facing most participants for various reasons. This finding illustrates that further efforts are required to design and construct better alternatives, such as the proposed educational chemistry system designed to simulate experiments and visualise molecules to clarify and explain the results. Providing such an option offers the convenience of simulated laboratory experiments that can be conducted anywhere and anytime. Moreover, the system can enrich and improve education by providing a more effective learning experience that keeps students motivated and engaged during the learning process.

The results indicate that the participants prefer the notion of merging the concepts of experiment simulation and molecular visualisation, with some clarification to assist the students in comprehending the main concepts of the experiments. The teachers described the proposed educational system as an accurate, efficient and realistic simulation. Furthermore, the findings indicate that most participants found the educational system simple and straightforward and believed that students could complete tasks easily without help. Interviewee 4 noted that a user guide should be made available.

Interviewee 4 stated, '*Maybe some students need the user manual.*'

Interviewee 3 remarked, '*It is easy to use, but you need to practise to be professional.*'

The results demonstrate that the available systems provide only one level of chemistry concepts, the macroscopic or microscopic level. The systems present the molecular structures or experiments through videos or simulation and do not combine these two views. In contrast, the proposed educational system integrates both chemistry concepts to provide students with the knowledge and skills needed to understand them.

Interviewee 1 stated:

> *It will help students to understand the concepts of the experiments. It obviates the need for a theoretical explanation and applying the experiments in labs. Especially, we cannot apply all the lab experiments. In some experiments, I am the only one who can do it, and students can just watch me. However, this application can help everyone to do the experiments.*

Interviewee 2 said:

> *It will help students to understand the concepts of the experiments. Because after doing the experiment, the user can explore and recognise the chemical compounds and understand what happened to the bonds between atoms.*

Therefore, using such a system in a chemistry class can enable students to perform experiment steps and view the molecular explanations, driving an understanding of chemistry theory through a combination of the macroscopic and microscopic levels.

According to the interviewees, the available systems have significant limitations, such as lack of interaction and low-fidelity simulation. In contrast, the proposed educational system uses the Leap Motion controller, which provides gesture-based interaction and simulates hand movements. Accordingly, the system provides a more realistic interaction and simulation, making it more appreciated by teachers.

> Interviewee 5 stated, '*I have liked the Leap Motion controller as a new device as it helps to simulate the movement of the hand.*'

> Interviewee 2 said about the Leap Motion controller, *'It is better because the student can practise as if she is in a real lab.*'

> Interviewee 3 reported, '*It provides more simulated reality.*'

> Finally, Interviewee 1 stated, '*It is unique and provides more interaction.'*

The problems and obstacles faced by teachers in practical chemistry teaching are worth noting. The interview findings suggest that the proposed system can mitigate challenges, such as material shortages, exam preparation needs, experiment duplication, class size increases and school test planning.

> Interviewee 3 noted, '*I can use the system only without doing the experiments in the real laboratory. Especially, if tools or materials are unavailable or some of the material may cause danger to students.*'

Moreover, the findings revealed that participants like the system interface and virtual chemistry laboratory and most liked how the designs and colours of the tools, compounds and materials were close to reality. Most of the participants preferred the 3D visualisation, which helps users understand the molecular explanation of the experiment because they can easily scan and discover molecular structures at each experiment step.

Although none of the participants had used the Leap Motion controller before, most preferred it to the mouse because it offers a more realistic and immersive interaction with the interface, simulating hand movements.

The participants found the mouse is simpler to use and provides faster interactivity, but it is less engaging than the Leap Motion controller.

> Interviewee 3 stated, '*The mouse is a good and available device, but the Leap Motion controller is better and provides more simulated reality.*'

> Interviewee 4 said, '*The Leap Motion controller is an amazing new device. It makes the application more effective while the mouse is an easy-to-use and fast device.*'

Overall, the results from the interviews demonstrate that the participants strongly support and like the proposed educational system and found it useful, rating it either 4 or 5 (out of 5). This outcome demonstrates that the system is a valuable application that can assist in teaching processes by allowing students to conduct chemistry experiments and helping them understand the concepts involved. In addition, the participants highlighted the need to provide the interface in Arabic for the students, so the developed educational system was updated, and this feature was added to the interface. After this study, this interface was added to the educational system before conducting the experimental study in the secondary school. Moreover, most participants stated that more experiments should be included in the system to cover the curriculum for secondary school chemistry.

> Interviewee 5 remarked, '*I wish the system had included additional experiments.*'

> Interviewee 2 noted, '*I feel it can include more experiments and more complicated subjects.*'

6.2.4 Conclusion

This interview study found that participants had previous experience using e-learning systems in teaching chemistry. The interview study results indicated that many available educational systems exist, but they have several limitations. The existing systems do not integrate the macroscopic and microscopic levels of chemistry concepts. The findings indicate that most of the available education systems provide basic interaction and lack realistic simulation.

Chemistry teachers need a useful educational system to overcome the difficulties posed by the students in conducting all the experiments in a laboratory. Furthermore, teachers face diverse problems, such as a lack of materials, the risk of conducting certain experiments that might harm students, and the increasing class sizes. In addition, one of the findings of this study is that students have difficulties learning molecular structures and chemical bonds.

The findings indicate that the participants like how this system merges molecular visualisation, explanations and practical experiences to understand chemistry concepts. This integration can improve chemistry teaching and help conduct laboratory experiments for secondary school students. The study reveals that the proposed educational system is helpful in increasing student interactions and delivering a realistic simulation. In addition, the participants were confident that students could easily use the system to acquire the knowledge and skills needed to comprehend chemistry concepts. Although the Leap Motion controller was not familiar to the participants, they preferred it to the mouse because it offered more interaction and realistic simulation than the mouse.

6.3 System Usability Testing

The second phase of studying and testing the educational system involved usability testing, which allowed volunteer users to use the system and assess its usability. The study results were analysed to examine and evaluate the interface design of the system and its representation of knowledge and information. Each participant completed a survey about their experience using the system. The information gathered on the participants' opinions and behaviours was analysed to discover reactions and attitudes, measure user satisfaction, gauge users' opinions of the system, and add credibility to the research.

6.3.1 Methodology

The methodologies of the usability testing were discussed in Chapter 4. The usability testing for the system was conducted in November 2015, and the system was tested using two different configurations, depending on the input device. The Leap Motion controller configuration is denoted by LM_DEVICE, and the mouse configuration is denoted as MOUSE_DEVICE. In the first configuration, the gesture-based Leap Motion controller was set and used as an input device for users to interact with the system interface. Conversely, in the second configuration, the mouse was set as the input device for participants to interact with the system.

6.3.1.1 Participants

The participants were divided equally into two groups, with 45 participating in the MOUSE_DEVICE testing and 45 participating in the LM_DEVICE testing. All participants were female because PNU is a single-sex university. They were between 18 and 24 years old. Within the LM_DEVICE group, 34 users tested the proposed educational system on 22 November 2015, and 11 users tested it on 23 November 2015. Within the MOUSE_DEVICE group, 22 users participated on 23 November 2015, and 23 participated on 24 November 2015.Table 6-2 indicates that 81 participants were high school graduates and 9 participants had bachelor's degrees. Further, 53 participants used a computer in their daily lives, and 30 used one often. Moreover, 33 participants rated their computer skills as 'excellent', and 51 rated their skills as 'good'. Six rated their skills as 'fair'. Finally, 25 participants had previously used a simulation learning system, whereas 65 had not.

Type of input device	Number of samples			
Leap Motion controller	45			
Mouse	45			
Both	90			
	What is your age?			
	18-24 years old			
Leap Motion controller	45			
Mouse	45			
Both	90			
	What is your gender?			
	Female			
Leap Motion controller	45			
Mouse	45			
Both	90			
	What is your current level of education?			
	High school graduate	Bachelor's degree		
Leap Motion controller	41	4		
Mouse	40	5		
Both	81	9		
	How often do you use the computer?			
	Rarely	Occasionally	Often	Always
Leap Motion controller	0	3	17	25
Mouse	1	3.0	13	28
Both	1	6	30	53
	How would you rate your computer skills?			
	Fair	Good	Excellent	
Leap Motion controller	2	27	16	
Mouse	4	24	17	
Both	6	51	33	
	Have you use any simulation learning system before?			
	Yes	No		
Leap Motion controller	10	35		
Mouse	15	30		
Both	25	65		

Table 6-2 Participant demographics.

6.3.1.2 Sessions

Participants were invited individually to the testing administrator's office. Each individual session lasted approximately 10 minutes, during which the proposed system's purpose and functions were explained to the participant. Then, the participant tried the system using only one of the input devices, the mouse or Leap Motion controller. The testing administrator was present when the participant conducted a test of the system. After finishing the tasks, the participants completed a survey, which is presented in Appendix E. The participants responded to a short background questionnaire and the following 13 subjective measures:

1. I thought the system was easy to use.
2. I immediately understood the function of the system.
3. I feel that I successfully completed all the tasks.
4. The tasks were easy to complete.
5. The input device helped with my task completion.
6. It was easy to use this device.
7. I feel comfortable using this input device.
8. I like the interface of this system.
9. It was easy moving from the macroscopic view to the microscopic view.
10. The information provided for the system is easy to understand.
11. I think the system will be effective in helping me understand the experiment tasks and scenarios.
12. I would imagine that most people would learn to use this system very quickly.
13. I think that I would like to use this system again.

6.3.2 Results and discussion

Overall, all tasks were successfully completed by all participants. Table 6-3 and Figures 6-4 to 6-16 present the usability testing results in more detail. According to 91.78% of the participants, the system was easy to use, whereas 90.44% liked the system interface, and 91.33% were interested in using the system again. Furthermore, 91.56% of participants believed the system was very useful in assisting them in comprehending the main concepts of the experiment tasks and scenarios, and 88.67% felt that transforming from the macroscopic to the microscopic view was easy.

In the LM_DEVICE configuration, when participants tested the system and interacted with its interface via the Leap Motion controller, most (92.89%) either agreed or strongly agreed that it was easy to use and knew how the system worked immediately. The majority of the participants (81.78%) agreed that they were able to complete all tasks successfully, and most agreed that the tasks were straightforward to complete (87.56%) and that the Leap Motion controller helped with the task completion (84.44%).

The results demonstrate that the Leap Motion controller was easy to use, as agreed by most participants (92.89%). Moreover, 85.78% agreed that using the Leap Motion controller felt comfortable, and most (89.78%) agreed that the system would be very useful in assisting them to comprehend the experiment tasks and scenarios. Furthermore, the majority (91.11%) liked the system interface, and 93.33% indicated an interest in using the system again.

The results indicate that most participants understood and performed tasks easily using the Leap Motion controller. Therefore, the Leap Motion controller is easy to use even for those unfamiliar with it. Furthermore, the Leap Motion controller can help make application user interfaces more natural using movements familiar to the user to control the application.

All MOUSE_DEVICE participants tested the system using the mouse to interact with the interface. Most participants (90.67%) agreed that the system functions were understood immediately and easily. Furthermore, most participants agreed that the mouse assisted in completing the task and that the tasks were easy to complete. The majority of participants agreed that it was easy to use the mouse (92.44%), and they liked the system interface (89.78%) and expressed interest in using the system again (89.33%).

Overall, 92.89% of the LM_DEVICE users agreed that it was easy to use the system, a higher agreement percentage than for the MOUSE_DEVICE (90.67%), as depicted in Figure 6-17. Although more participants agreed that the system functions were immediately understood and that all tasks were completed successfully in the MOUSE_DEVICE, as presented in Figures 6-5 and 6-6, a higher percentage of LM_DEVICE users agreed that the device was easy to use. As illustrated in Figure 6-17, approximately the same percentage of participants for both configurations agreed that they felt comfortable while interacting with the system through this input device and that it was straightforward to move from the macroscopic to the microscopic view. In contrast, for the LM_DEVICE, 91.11% of participants liked the system interface, a higher percentage than for the MOUSE_DEVICE. Furthermore, 93.33% of participants indicated an interest in using the system again in the LM_DEVICE, whereas only 89.33% did so in the MOUSE_DEVICE. This result demonstrates that the potential to engage users with chemistry experiments is potentially higher with the Leap Motion controller.

The reliability of the usability test for both devices was evaluated using Cronbach's alpha test. As seen in Table 6-4, the alpha value is greater than 0.9, which indicate that the study is reliable.

Statement	Type of input device	1 Strongly disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly agree	Mean Rating	Percent Agree
1. I thought the system was easy to use	Leap Motion controller	0	0	1	14	30	**4.64**	**92.89**
	Mouse	0	1	4	10	30	**4.53**	**90.67**
	Both	0	1	5	24	60	**4.59**	**91.78**
2. I immediately understood the function of the system	Leap Motion controller	0	1	4	16	24	**4.40**	**88.00**
	Mouse	0	1	2	14	28	**4.53**	**90.67**
	Both	0	2	6	30	52	**4.47**	**89.33**
3. I feel that I successfully completed all the tasks	Leap Motion controller	0	2	8	19	16	**4.09**	**81.78**
	Mouse	0	1	5	16	23	**4.36**	**87.11**
	Both	0	3	13	35	39	**4.22**	**84.44**
4. The tasks were easy to complete	Leap Motion controller	0	0	5	18	22	**4.38**	**87.56**
	Mouse	0	1	4	10	30	**4.53**	**90.67**
	Both	0	1	9	28	52	**4.46**	**89.11**
5. The input device helped with my task completion	Leap Motion controller	0	1	7	18	19	**4.22**	**84.44**
	Mouse	0	1	3	13	28	**4.51**	**90.22**
	Both	0	2	10	31	47	**4.37**	**87.33**
6. It was easy to use this device	Leap Motion controller	0	1	1	11	32	**4.64**	**92.89**
	Mouse	0	0	3	11	31	**4.62**	**92.44**
	Both	0	1	4	22	63	**4.63**	**92.67**
7. I feel comfortable using this input device.	Leap Motion controller	0	0	7	18	20	**4.29**	**85.78**
	Mouse	0	1	7	12	25	**4.36**	**87.11**
	Both	0	1	14	30	45	**4.32**	**86.44**
8. I like the interface of this system	Leap Motion controller	0	1	4	9	31	**4.56**	**91.11**
	Mouse	0	1	3	14	27	**4.49**	**89.78**
	Both	0	2	7	23	58	**4.52**	**90.44**
9. It was easy moving from the macroscopic view to the microscopic view	Leap Motion controller	0	1	4	15	25	**4.42**	**88.44**
	Mouse	0	1	4	14	26	**4.44**	**88.89**
	Both	0	2	8	29	51	**4.43**	**88.67**
10. The information provided for the system is easy to understand	Leap Motion controller	0	1	5	19	20	**4.29**	**85.78**
	Mouse	0	0	2	13	30	**4.62**	**92.44**
	Both	0	1	7	32	50	**4.46**	**89.11**
11. I think the system will be effective in helping me understand the experiments' tasks and scenarios	Leap Motion controller	0	0	5	13	27	**4.49**	**89.78**
	Mouse	0	0	2	11	32	**4.67**	**93.33**
	Both	0	0	7	24	59	**4.58**	**91.56**
12. I would imagine that most people would learn to use this system very quickly	Leap Motion controller	0	1	6	17	21	**4.29**	**85.78**
	Mouse	0	1	4	9	31	**4.56**	**91.11**
	Both	0	2	10	26	52	**4.42**	**88.44**
13. I think that I would like to use this system again	Leap Motion controller	0	0	1	13	31	**4.67**	**93.33**
	Mouse	0	1	6	9	29	**4.47**	**89.33**
	Both	0	1	7	22	60	**4.57**	**91.33**
Total	Leap Motion controller	0	9	58	200	318	**4.41**	**88.27**
	Mouse	0	10	49	156	370	**4.51**	**90.29**
	Both	0	19	107	356	688	**4.46**	**89.28**

Table 6-3 Results of the system usability test.

Reliability Statistics	
Cronbach's Alpha	N of Items
.984	13

Table 6-4 Reliability statistics of the usability testing using Cronbach's alpha.

6.3.2.1 Comparative study of the system usability testing for the two input devices

The results of the comparative study for the two devices based on the mean rating and percentage of agreement demonstrate that the MOUSE_DEVICE was rated marginally higher than the LM_DEVICE, with just a small gap between them, as depicted in Figures 6-17 and 6-18. The mean agreement ratings for the MOUSE_DEVICE and LM_DEVICE were 4.51 and 4.41, respectively.

Moreover, a comparative study was conducted to study the differences between the mean agreement rate of the LM_DEVICE and MOUSE_DEVICE for each usability testing measure using a inferential statistical test (t-test), where the significance level was 5% ($p < 0.05$). The hypothesis, in this study, was that the LM_DEVICE provides usability scores better than the MOUSE_DEVICE in all the measures. Table 6-5 presents the results of the LM_DEVICE and MOUSE_DEVICE for each usability testing measure and Table 6-6 and Figure 6-18 illustrates the results of the independent samples t-test between the mean agreement rate of the LM_DEVICE and MOUSE_DEVICE. In the following, the study results are presented for each measure.

1. **I thought the system was easy to use**

In the first measure of the system usability testing for the LM_DEVICE, the mean agreement rate was 4.644, and the standard deviation was 0.528. The corresponding values were 4.533 and 0.756 for MOUSE_DEVICE. Table 6-5 illustrates the LM_DEVICE and

MOUSE_DEVICE results in the first measure of the system usability testing. Results of the independent samples t-test showed that the mean difference between the LM_DEVICE and MOUSE_DEVICE was not statistically significant at the .05 level of significance ($t(88)= .807$, $p=.422$; see Table 6-6 and Figure 6-18). Although most participants agreed that the system was easy to use with the Leap Motion controller, there was no significant difference between the results of the two groups.

2. **I immediately understood the function of the system**

In the second measure of the system usability testing, the means and standard deviations were 4.400 and 0.750 for the LM_DEVICE, 4.533 and 0.694 for the MOUSE_DEVICE, respectively (see Table 6-5). No significant difference was found between the mean agreement rate of the LM_DEVICE and MOUSE_DEVICE ($t(88)= -.875$, $p=.384$) according to the independent samples t-test results (see Table 6-6 and Figure 6-18). Therefore, there was no significant difference between the results of the two groups while more participants agreed that they immediately understood the function of the system with the mouse than with Leap Motion controller.

3. **I feel that I successfully completed all the tasks**

In this measure of the system usability testing for the LM_DEVICE, the mean agreement rate was 4.088, and the standard deviation was 0.848. The equivalent values were 4.355 and 0.773 for MOUSE_DEVICE (see Table 6-5). The independent samples t-test results indicated no significant difference between the mean agreement rate of the LM_DEVICE and MOUSE_DEVICE ($t(88)= -1.559$, $p=.123$; see Table 6-6 and Figure 6-18). However, more participants agreed to feel that they successfully completed all the tasks with the mouse than with Leap Motion controller.

4. The tasks were easy to complete

The means and standard deviations were 4.377 and 0.683 for the LM_DEVICE, 4.533 and 0.756 for the MOUSE_DEVICE, respectively in this measure (see Table 6-5). Although more participants agreed that the tasks were easy to complete with the mouse than with the Leap Motion controller, the independent samples t-test results showed no significant difference between the means of the LM_DEVICE and MOUSE_DEVICE ($t(88)= -1.023$, $p=.309$; see Table 6-6 and Figure 6-18).

5. The input device helped with my task completion

In this statement measure of the testing for the LM_DEVICE, the mean agreement rate was 4.222, and the standard deviation was 0.794. The corresponding values were 4.511 and 0.726 for MOUSE_DEVICE (see Table 6-5). While no significant difference was found between the mean agreement rate of the LM_DEVICE and MOUSE_DEVICE ($t(88)= -1.800$, $p=.075$) according to the independent samples t-test results (see Table 6-6 and Figure 6-18), more participants agreed that the input device helped with their task completion with the mouse than with the Leap Motion controller.

6. It was easy to use this device

The means and standard deviations were 4.644 and 0.645 for the LM_DEVICE, 4.622 and 0.613 for the MOUSE_DEVICE, respectively in this usability testing measure (see Table 6-5). The independent samples t-test results indicated no significant differences between the mean agreement rate of the LM_DEVICE and MOUSE_DEVICE ($t(88)= .167$, $p=.867$; see Table 6-6 and Figure 6-18). However, more participants agreed that it was easy to use the Leap Motion controller than the mouse.

7. I feel comfortable using this input device

The mean agreement rate was 4.288, and the standard deviation was 0.726 in this measure of the testing for the LM_DEVICE. The equivalent values were 4.355 and 0.829 for MOUSE_DEVICE (see Table 6-5). No significant difference was found between the mean agreement rate of the LM_DEVICE and MOUSE_DEVICE ($t(88)= -.405$, $p=.686$) according to the independent samples t-test results (see Table 6-6 and Figure 6-18). Therefore, there was no significant difference between the results of the two groups while more participants agreed that they feel comfortable using the mouse than the Leap Motion controller.

8. I like the interface of this system

The means and standard deviations were 4.555 and 0.755 for the LM_DEVICE, 4.488 and 0.726 for the MOUSE_DEVICE, respectively in this measure (see Table 6-5). The independent samples t-test results showed no significant difference between the mean agreement rate of the LM_DEVICE and MOUSE_DEVICE ($t(88)=.427$, $p=.671$; see Table 6-6 and Figure 6-18). However, more participants agreed that they like the interface of this system with the Leap Motion controller than with the mouse.

9. It was easy moving from the macroscopic view to the microscopic view

The means and standard deviations were 4.422 and 0.753 for the LM_DEVICE, 4.444 and 0.755 for the MOUSE_DEVICE, respectively in this measure (see Table 6-5). According to the independent samples t-test results, no significant difference was found between the mean agreement rate of the LM_DEVICE and MOUSE_DEVICE ($t(88)= -.140$, $p=.889$; see Table 6-6 and Figure 6-18). Nevertheless, more participants agreed that it was easy moving from the macroscopic view to the microscopic view with the mouse than with Leap Motion controller.

10. The information provided for the system is easy to understand

The mean agreement rate was 4.288, and the standard deviation was 0.757 in this measure of the testing for the LM_DEVICE. The equivalent values were 4.622 and 0.575 for MOUSE_DEVICE (see Table 6-5). The independent samples t-test results identified a significant difference between the mean agreement rate of the LM_DEVICE and MOUSE_DEVICE ($t(88)= -2.350$, $p=.021$; see Table 6-6 and Figure 6-18). Therefore, the results indicated that the information provided for the system is easy to understand with the mouse more than with the Leap Motion controller.

11. I think the system will be effective in helping me understand the experiment tasks and scenarios

For the LM_DEVICE, the mean was 4.488, and the standard deviation was 0.694. The corresponding values were 4.666 and 0.564 for MOUSE_DEVICE in this measure (see Table 6-5). Results of the independent samples t-test determined that the mean agreement rate difference between the LM_DEVICE and MOUSE_DEVICE was not statistically significant ($t(88)= -1.332$, $p=.186$; see Table 6-6 and Figure 6-18). While there no significant difference between the results of the two groups, more participants agreed the system will be effective in helping me understand the experiment tasks and scenarios with the mouse than with the Leap Motion controller.

12. I would imagine that most people would learn to use this system very quickly

In this usability testing measure, the means and standard deviations were 4.288 and 0.786 for the LM_DEVICE, 4.555 and 0.755 for the MOUSE_DEVICE, respectively (see Table 6-5). The independent samples t-test results showed no significant difference between the mean agreement rate of the LM_DEVICE and MOUSE_DEVICE ($t(88)= -1.640$, $p=.105$; see Table 6-6 and Figure 6-18). However, more participants agreed that they would imagine that most people would learn to use this system very quickly with the mouse than with the Leap Motion controller.

13. I think that I would like to use this system again

The means and standard deviations were 4.666 and 0.522 for the LM_DEVICE, 4.466 and 0.814 for the MOUSE_DEVICE, respectively in this measure (see Table 6-5). No significant difference was found between the mean agreement rate of the LM_DEVICE and MOUSE_DEVICE ($t(88)= 1.386$, $p=.169$) based on the independent samples t-test results (see Table 6-6 and Figure 6-18). Nevertheless, more participants agreed that they would like to use this system again with Leap Motion controller than with the mouse.

In summary, the results of the LM_DEVICE and MOUSE_DEVICE are very close. More participants using the MOUSE_DEVICE felt comfortable using the mouse, and it helped them successfully complete all tasks, an expected result because the mouse is the most common input device in the computer world, and all participants were more familiar with it. Although the Leap Motion controller had never previously been used by any participants, most participants agreed that it was convenient, simple and straightforward. More participants in the LM_DEVICE liked the system interface, and they expressed interest in using the system again. This suggests that users are more interested in using the Leap Motion controller with the system because it gave them a greater comprehension of the main concepts of the experiments. These findings are based on the mean rating and percentage of agreement, while the inferential statistical tests showed no significant differences between the LM_DEVICE and MOUSE_DEVICE in 12 of the system usability testing measures. However, there is a statistical difference between the two groups, the LM_DEVICE and MOUSE_DEVICE, for the information provided for the system is easy to understand measure. The results indicate that more participants agreed with the mouse than with the

Leap Motion controller, which may be due to all participants being more familiar with the mouse.

Statement Measure		Device	N	Mean	Std. Deviation	Std. Error Mean
1.	I thought the system was easy to use	Leap Motion controller	45	4.6444	.52896	.07885
		Mouse	45	4.5333	.75679	.11282
2.	I immediately understood the function of the system	Leap Motion controller	45	4.4000	.75076	.11192
		Mouse	45	4.5333	.69413	.10347
3.	I feel that I successfully completed all the tasks	Leap Motion controller	45	4.0889	.84805	.12642
		Mouse	45	4.3556	.77329	.11528
4.	The tasks were easy to complete	Leap Motion controller	45	4.3778	.68387	.10195
		Mouse	45	4.5333	.75679	.11282
5.	The input device helped with my task completion	Leap Motion controller	45	4.2222	.79455	.11844
		Mouse	45	4.5111	.72683	.10835
6.	It was easy to use this device	Leap Motion controller	45	4.6444	.64511	.09617
		Mouse	45	4.6222	.61381	.09150
7.	I feel comfortable using this input device	Leap Motion controller	45	4.2889	.72683	.10835
		Mouse	45	4.3556	.82999	.12373
8.	I like the interface of this system	Leap Motion controller	45	4.5556	.75545	.11262
		Mouse	45	4.4889	.72683	.10835
9.	It was easy moving from the macroscopic view to the microscopic view	Leap Motion controller	45	4.4222	.75344	.11232
		Mouse	45	4.4444	.75545	.11262
10.	The information provided for the system is easy to understand	Leap Motion controller	45	4.2889	.75745	.11291
		Mouse	45	4.6222	.57560	.08581
11.	I think the system will be effective in helping me understand the experiment tasks and scenarios	Leap Motion controller	45	4.4889	.69486	.10358
		Mouse	45	4.6667	.56408	.08409
12.	I would imagine that most people would learn to use this system very quickly	Leap Motion controller	45	4.2889	.78689	.11730
		Mouse	45	4.5556	.75545	.11262
13.	I think that I would like to use this system again	Leap Motion controller	45	4.6667	.52223	.07785
		Mouse	45	4.4667	.81464	.12144

Table 6-5 Means, standard deviations and standard errors of all the LM_DEVICE and MOUSE_DEVICE for aggrement rate in each statement measure of the system usability testing.

Statement Measure	t-test for Equality of Means				
	t	Df	Sig.	Mean Difference	Std. Error Difference
1. I thought the system was easy to use	.807	88	.422	.11111	.13764
2. I immediately understood the function of the system	-.875	88	.384	-.13333	.15242
3. I feel that I successfully completed all the tasks	-1.559	88	.123	-.26667	.17109
4. The tasks were easy to complete	-1.023	88	.309	-.15556	.15205
5. The input device helped with my task completion	-1.800	88	.075	-.28889	.16053
6. It was easy to use this device	.167	88	.867	.02222	.13274
7. I feel comfortable using this input device	-.405	88	.686	-.06667	.16446
8. I like the interface of this system	.427	88	.671	.06667	.15628
9. It was easy moving from the macroscopic view to the microscopic view	-.140	88	.889	-.02222	.15905
10. The information provided for the system is easy to understand	-2.350	88	.021*	-.33333	.14182
11. I think the system will be effective in helping me understand the experiment tasks and scenarios	-1.332	88	.186	-.17778	.13342
12. I would imagine that most people would learn to use this system very quickly	-1.640	88	.105	-.26667	.16261
13. I think that I would like to use this system again	1.386	88	.169	.20000	.14425

Table 6-6 Comparisons of the mean agreement rates of the LM_DEVICE and MOUSE_DEVICE using the t-test for all the statement measures of the system usability testing. * Denotes statistical significance.

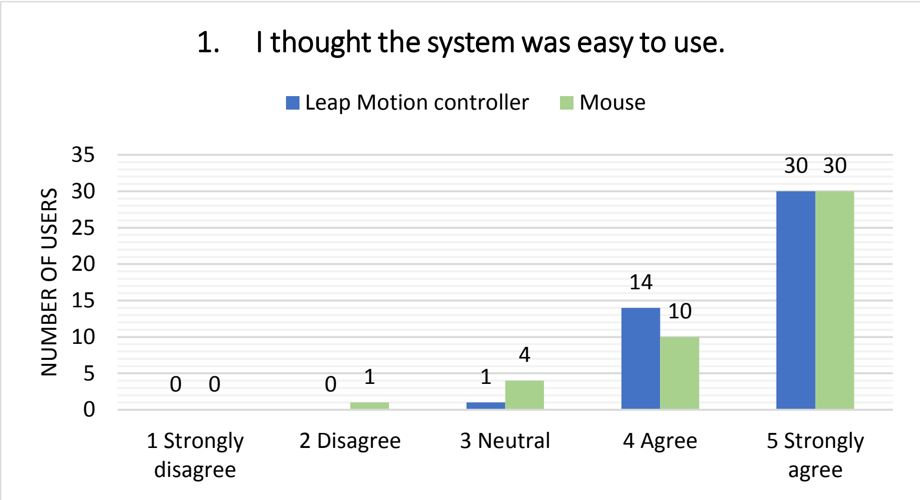


Figure 6-4 Agreement rate comparison between LM_DEVICE and MOUSE_DEVICE at Statement 1.

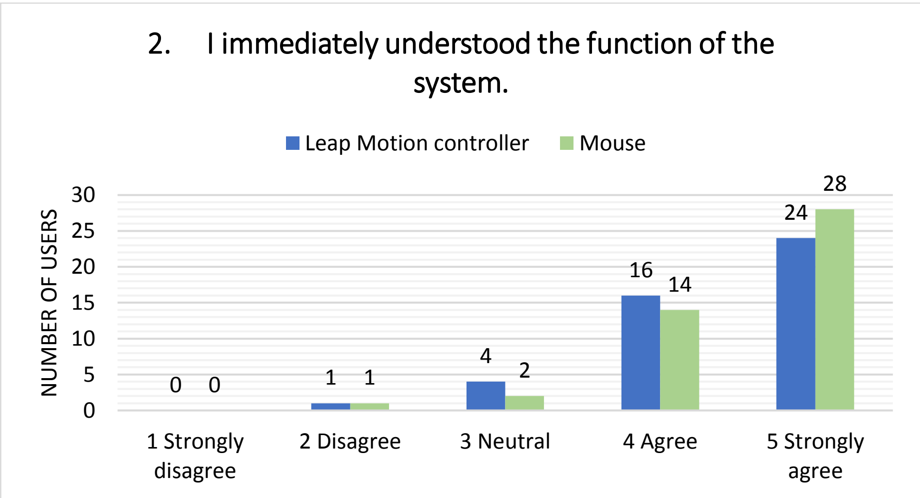


Figure 6-5 Agreement rate comparison between LM_DEVICE and MOUSE_DEVICE at Statement 2.

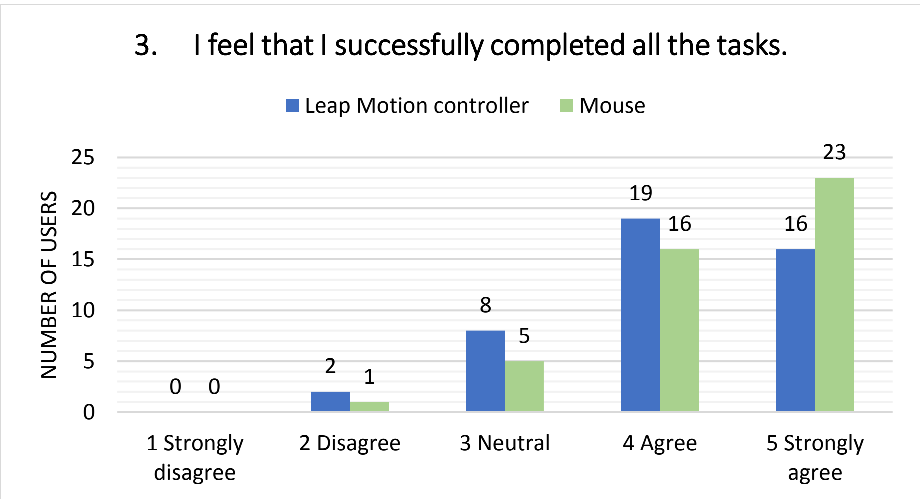


Figure 6-6 Agreement rate comparison between LM_DEVICE and MOUSE_DEVICE at Statement 3.

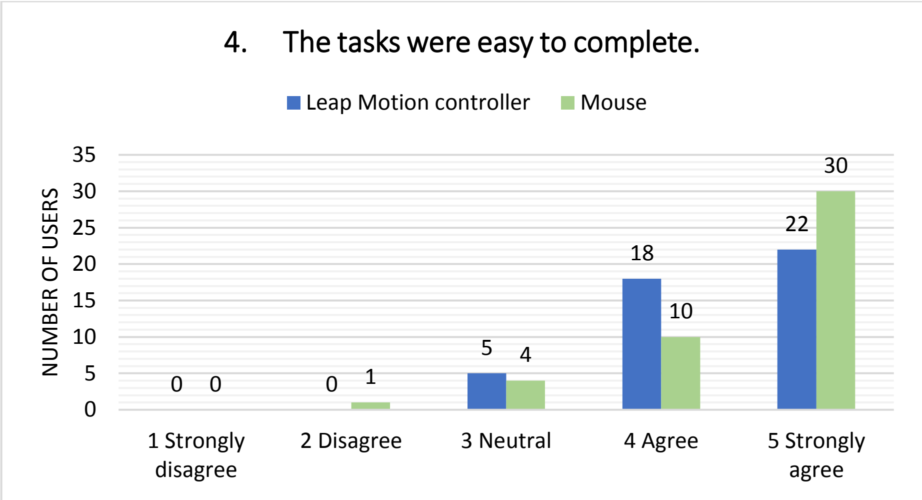


Figure 6-7 Agreement rate comparison between LM_DEVICE and MOUSE_DEVICE at Statement 4.

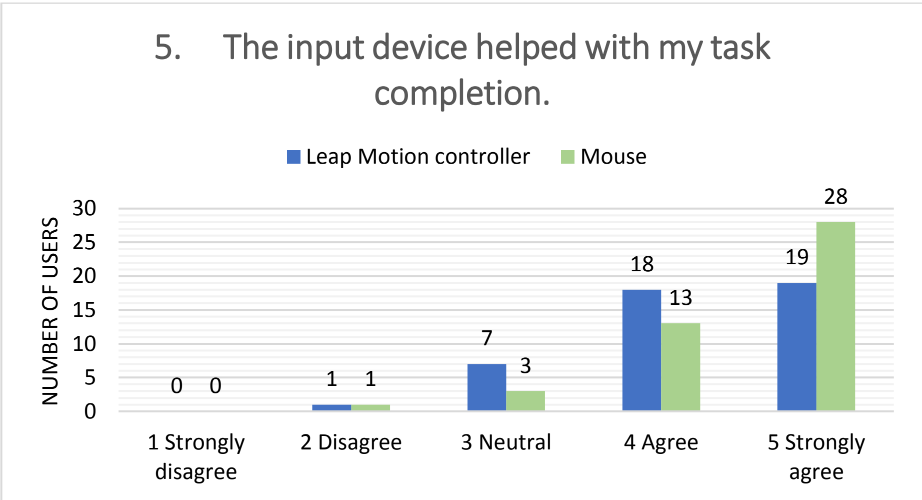


Figure 6-8 Agreement rate comparison between LM_DEVICE and MOUSE_DEVICE at Statement 5.

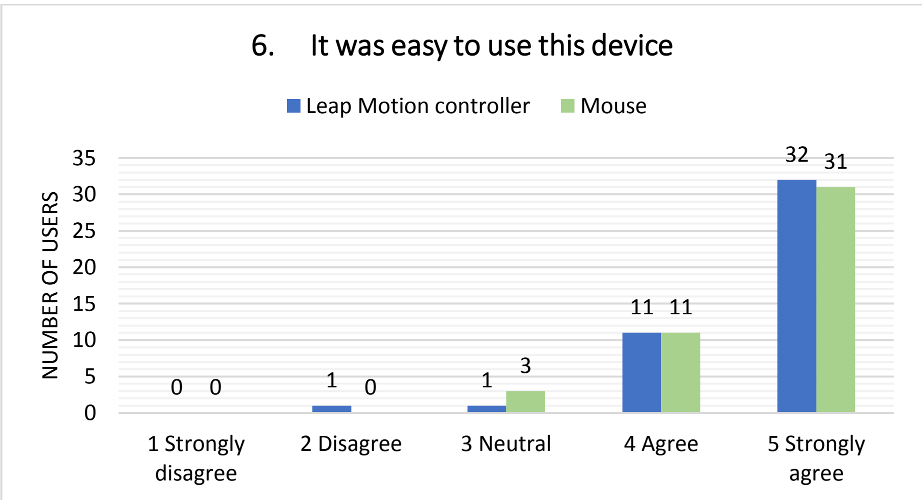


Figure 6-9 Agreement rate comparison between LM_DEVICE and MOUSE_DEVICE at Statement 6.

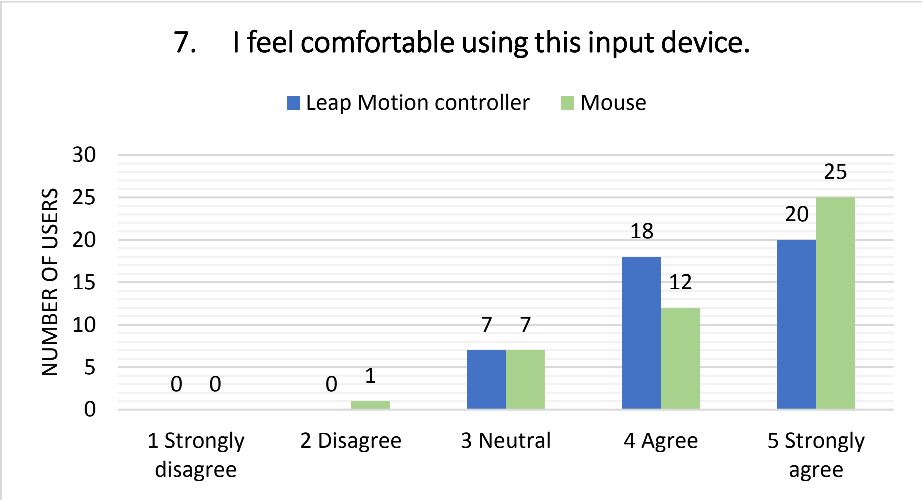


Figure 6-10 Agreement rate comparison between LM_DEVICE and MOUSE_DEVICE at Statement 7.

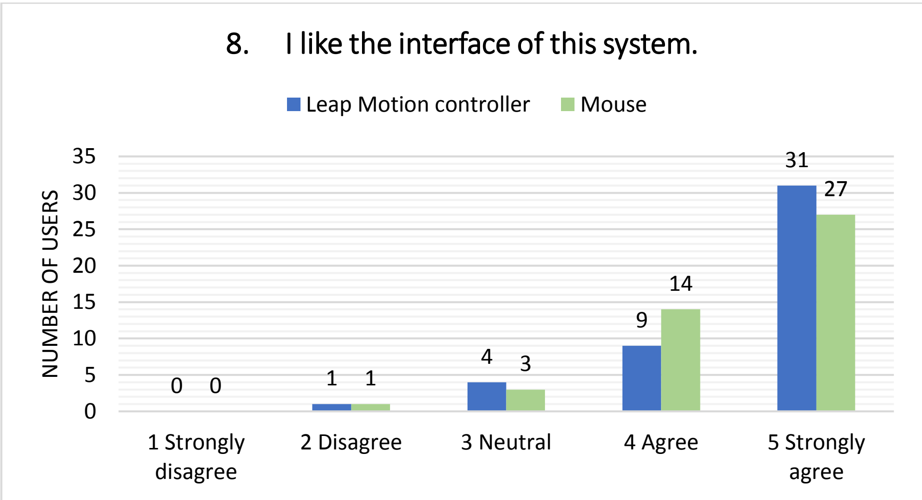


Figure 6-11 Agreement rate comparison between LM_DEVICE and MOUSE_DEVICE at Statement 8.

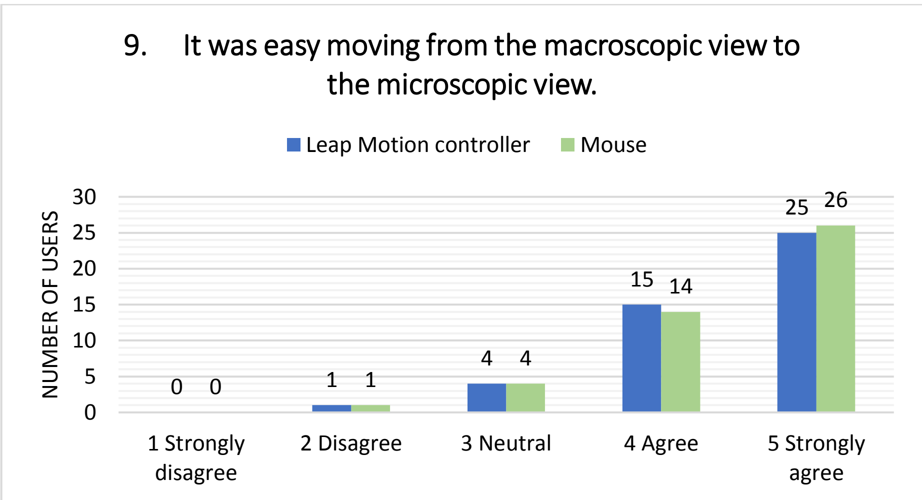


Figure 6-12 Agreement rate comparison between LM_DEVICE and MOUSE_DEVICE at Statement 9.

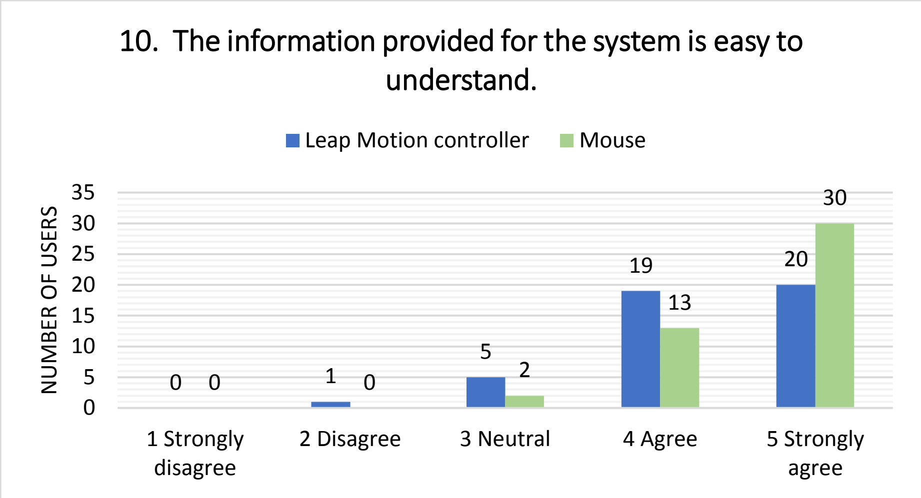


Figure 6-13 Agreement rate comparison between LM_DEVICE and MOUSE_DEVICE at Statement 10.

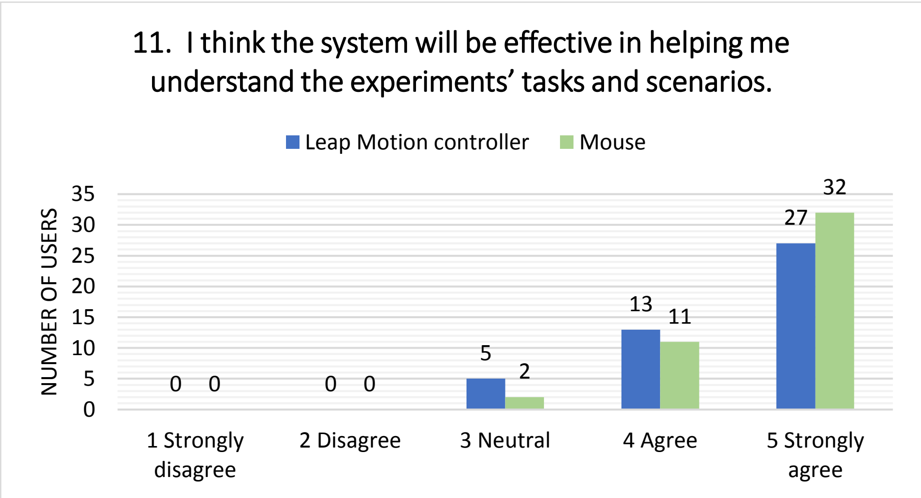


Figure 6-14 Agreement rate comparison between LM_DEVICE and MOUSE_DEVICE at Statement 11.

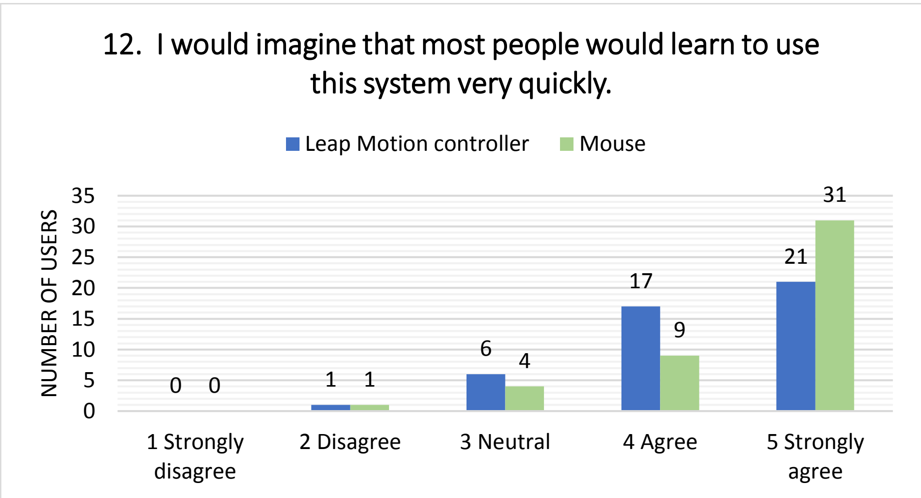


Figure 6-15 Agreement rate comparison between LM_DEVICE and MOUSE_DEVICE at Statement 12

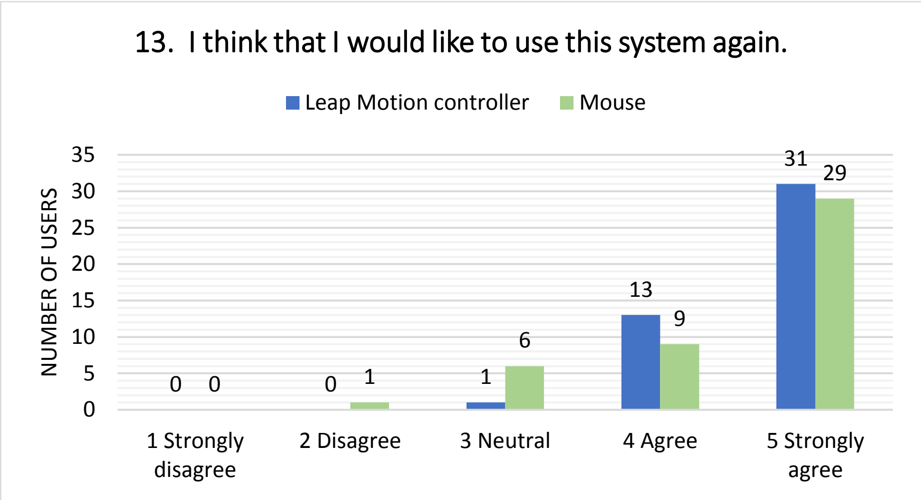


Figure 6-16 Agreement rate comparison between LM_DEVICE and MOUSE_DEVICE at Statement 13.

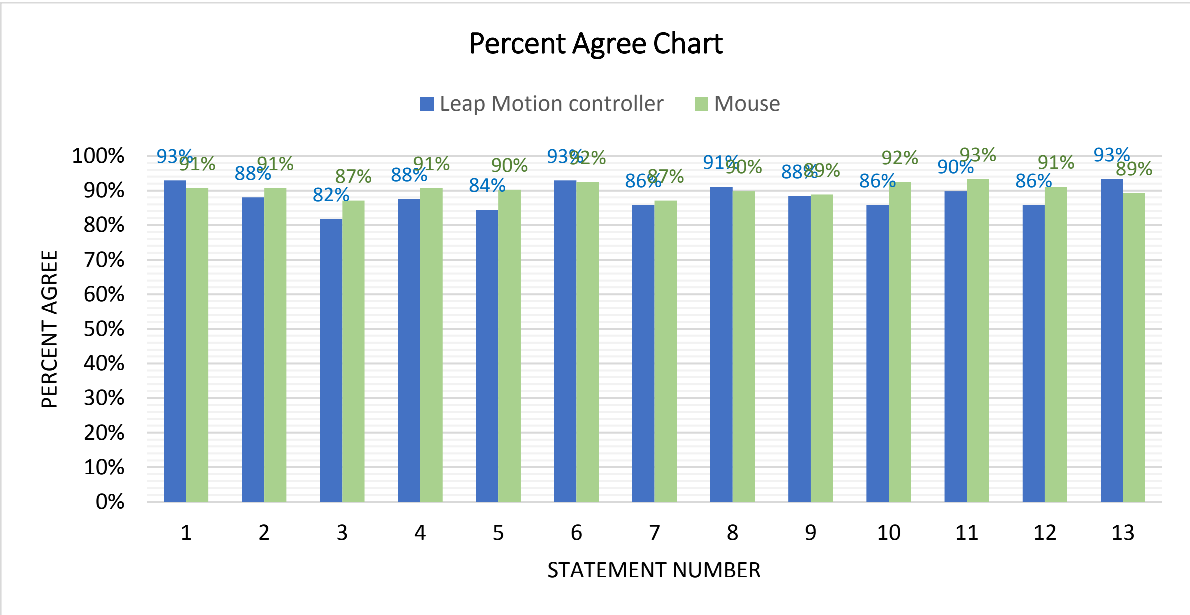


Figure 6-17 Comparing the percentage of agreement between LM_DEVICE and MOUSE_DEVICE.

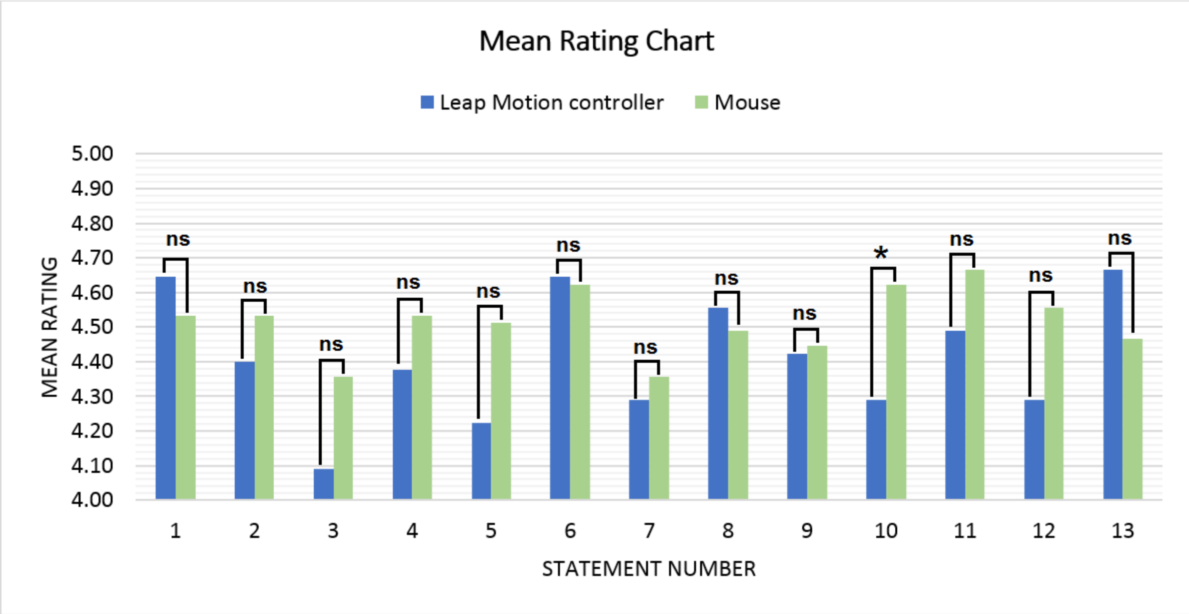


Figure 6-18 Mean rating comparison between LM_DEVICE and MOUSE_DEVICE. Asterisks denote significance levels: not significant (ns) $p > 0.05$ and * $p < 0.05$.

6.3.3 Conclusion

The system usability testing indicates that the proposed educational system is easy to use and that the tasks are easy to complete. The results indicate that the system is successful in helping the participants comprehend experiment tasks and scenarios and that the information provided for the system is easy to understand. Furthermore, most participants liked the system interface and expressed interest in using the system again.

Based on the comparative study results for the two input devices, the results of using the proposed system with the mouse are marginally higher than results using the system with the Leap Motion controller overall. In addition, more participants felt comfortable using the mouse because it is a common input device. However, more participants found the Leap Motion controller easier to use than the mouse and found the system easy to use, despite using it for the first time. In addition, more participants using the Leap Motion controller liked the system interface, and more participants in this group expressed interest in using the system again. However, these differences between the mean agreement rate of the system usability testing measures with the Leap Motion controller and the mouse were not statistically significant except for the statement measure ‘The information provided for the system is easy to understand'.

6.4 Chapter Summary

In this chapter, the proposed educational system was studied by interviewing experienced chemistry teachers after testing the system. Moreover, the system usability was studied through system testing with many voluntary users. These studies aim to acquire a better comprehension of user responses prior to testing the educational system in secondary schools.

This interview study results indicate that the teachers appreciate how the proposed educational system integrates simulation and molecular visualisation with gesture-based technology. The teachers confirmed the system’s capability to improve chemistry teaching in schools and help students understand chemistry concepts, finding that the proposed system can overcome their difficulties and the limitations of the available systems. Moreover, the teachers preferred the Leap Motion controller and confirmed that it provides a more realistic chemistry experiment simulation.

In the system usability testing, the participants provided positive feedback about the proposed educational system functionality and its usability. The results indicate that the system is easy to use and that the tasks were easy to complete. In addition, the proposed educational system can help participants understand the experiment tasks and scenarios, and the provided information is easy to understand. Furthermore, more participants liked the system interface with the Leap Motion controller and indicated that the system is easier to use with the Leap Motion controller. The results of the system usability testing using the Leap Motion controller and mouse are very close and no significant differences were found between them for 12 out of 13 subjective measures of the usability testing.

Chapter 7. EXPERIMENTAL STUDY

7.1 Introduction

This research uses an experimental method to examine the effects of an educational system that merges molecular visualisation and experiment simulations explicitly designed for the secondary school level. This experimental study is the third phase of the research to test the proposed educational system and assess the research hypothesis, as discussed in Chapter 4. The study primarily focuses on the ability of students to obtain and comprehend knowledge from the proposed system and attempts to explain its effects on chemistry education. This chapter describes the experiment performed in school to assess the effectiveness of the system for chemistry learners. The system was used to teach chemistry in secondary schools, and student knowledge of chemistry was examined. This chapter presents the experiment participants, procedures and analysis methods. Moreover, the study results and hypothesis testing are discussed. The experimental study procedures and results have been published in (Aldosari et al., in press)

7.2 Methodology

The methodologies of the experimental study were discussed in Chapter 4. The experimental conditions that changed between the first and second sets of lessons and experiments are referred to as Experiment 1 and Experiment 2 in the following sections.

In Experiment 1, all classes attended a theoretical lesson given by their usual chemistry teacher on mixing oil and water to study and understand the reason preventing water from blending with oil. After the lesson, the students in one class had only theoretical lessons, whereas the others applied their knowledge in a real-world chemistry laboratory or by using the proposed system with one of two input devices: the Leap Motion controller or mouse (see Figures 7-1 and 7-2).

In Experiment 2, the four classes repeated the procedures on a different subject, namely salt hydrolysis, to study and examine the reactions caused by adding salt to water and the colour changes caused by adding the universal indicator. Three types of salt are used, each with a different outcome (See Figures 7-3 and 7-4).

The conducted experimental study did not affect the actual teaching of the participating students. All participants have retaken the two lessons with their teachers and applied the lessons in a real laboratory as planned in their school's curriculum regardless of what they took in the experimental study. Two multiple-choice tests were used in this study as pretests and posttests for the two experiments. They were paper-based exams prepared by a secondary school chemistry teacher. The pretest and posttest were developed to measure the students' knowledge of chemistry and their understanding of chemistry experiments.

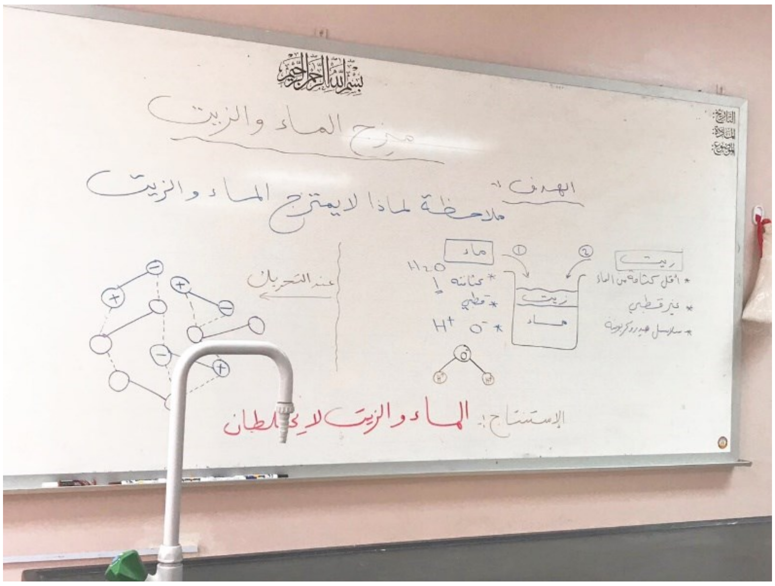


Figure 7-1 Photo of the whiteboard while students were learning the theoretical lesson of Experiment 1.

The pretests were used to assess prior student knowledge of the subject, and the posttests investigated student acquisition of conceptual knowledge and experimental skills from the lessons. Each question had five possible answers, of which only one was correct; three were distracters, and the last was ‘I do not know’, which was included to reduce the random chance of guessing a correct answer.

Figure 7-2 Photos of the laboratory while students were applying Experiment 1 in the real laboratory.

In Experiment 1, the test comprised five multiple-choice questions designed to determine student understanding of both the macroscopic and microscopic concepts of mixing oil and water. Three questions concerned experimental procedures in chemistry at the macroscopic level. Two questions assessed student understanding of the chemistry concepts involved and the microscopic view of the experiment.

Figure 7-3 Photos of the laboratory while students were applying Experiment 2 in the real laboratory.

Similarly, in Experiment 2, the test consisted of 14 multiple-choice questions designed to determine student understanding of both macroscopic and microscopic views of the second chemistry experiment on salt hydrolysis. The first four questions were designed to assess student participants' understanding of the chemistry experiments and the macroscopic view of the experiment. The remaining questions were used to assess their understanding of the chemistry experiment concepts and the microscopic view of the experiment. The questions in the two tests are available in Appendix F.

Figure 7-4 Photo of the classroom while students were applying Experiment 2 using the proposed system with the Leap Motion controller.

7.3 Participants

All students were female, and their average age was 17. All participants were in secondary school in Saudi Arabia and had a basic knowledge of chemistry (see Table 7-1).

Class	Class 1	Class 2	Class 3	Class 4
Number of students	26	28	29	30
Total	113			

Table 7-1 Number of secondary school students participating in this study.

7.4 Procedure

The whole experiment lasted two weeks. The experiment used four classes and alternated between classes in each case to guarantee that no student used the same system twice. During the first week, Experiment 1 was conducted. The participants were divided into four groups based on their classes: Class 1 (N = 26), Class 2 (N = 28), Class 3 (N = 29) and Class 4 (N = 30).

In the first stage, the students were given the pretest to assess their prior knowledge of the subject of Experiment 1 before attending the lesson. In the second stage, after the theoretical lesson, the four classes were assigned four different experimental conditions: Class 1 attended only the theoretical lesson without applying the concepts. Class 2 applied the theory in a chemistry experiment conducted in a real laboratory. Class 3 applied the theory in the proposed educational system using the Leap Motion controller, and Class 4 also applied the theory in the proposed educational system but used the mouse. In the third stage, all four classes took the posttest to evaluate what the students learnt.

In the second week, Experiment 2 was conducted. The participants were grouped as previously indicated. In the first stage, the students took the pretest to assess their prior knowledge of the subject of Experiment 2 before attending the lesson. After the theoretical lesson, Class 1 used the proposed educational system with the Leap Motion controller in the second stage. Class 2 used the proposed educational system with the mouse. Class 3 experimented in the real chemistry laboratory, and Class 4 only attended the theoretical lesson with no practical experience. In the third stage, all four classes again completed a posttest to measure their knowledge retention. The procedures followed in each experiment, the three stages of each experiment, and the arrangements of classes are presented in Figure 7-5.

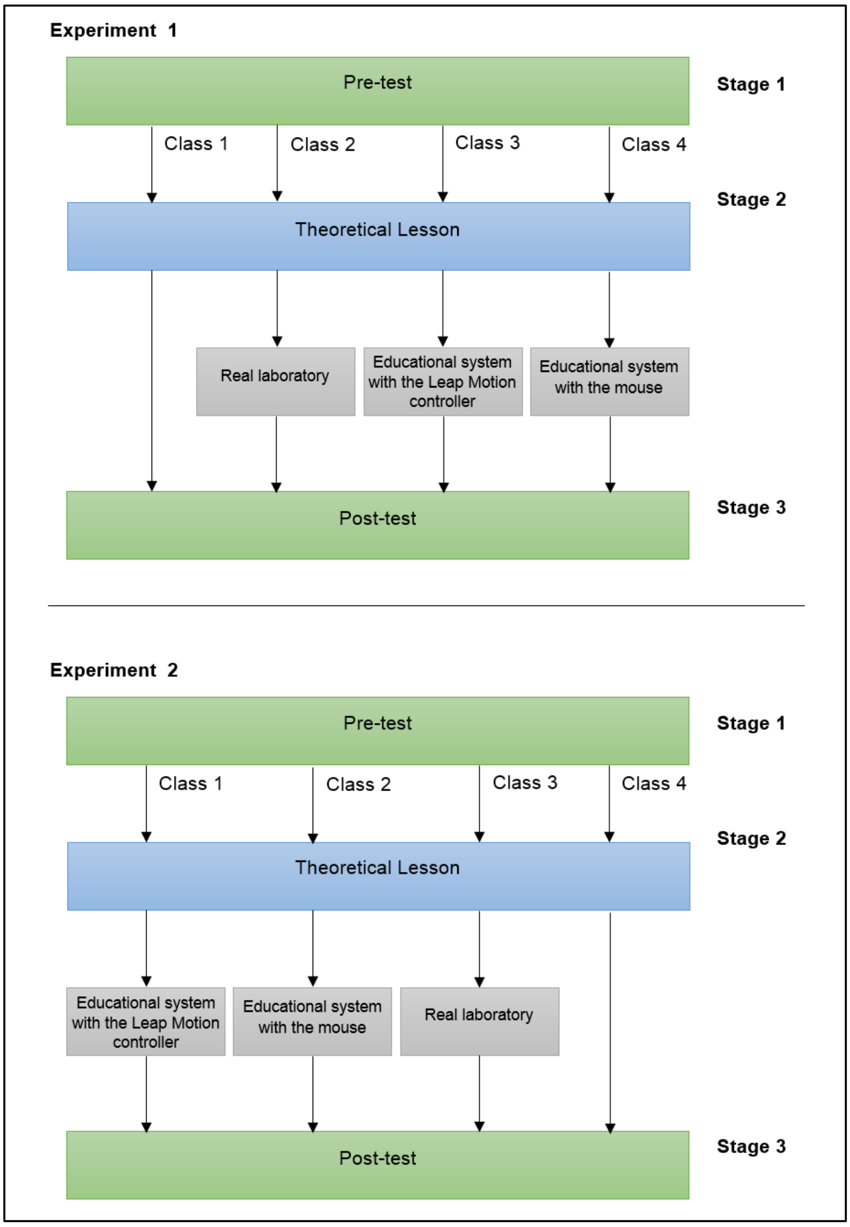


Figure 7-5 Test procedures, experiment stages, and class arrangements.

7.5 Data Analysis Process

In this study, the data analysis was conducted in two parts for each experiment to test two hypotheses. In the first part, the change in learning achievement for all posttest questions of the chemistry lessons was compared. The hypothesis was that using experiential learning favours the acquisition of chemistry concepts. The specific hypothesis is that experiential learning produces higher scores on the tests than the control group, demonstrating that the proposed system is comparable in terms of learning achievement with a real laboratory.

The second part compared the change in learning achievement in those questions related to knowledge of the macroscopic view of the chemistry lessons and those related to knowledge of the microscopic view. The hypothesis, in this case, was that the proposed educational system facilitates the learning of microscopic-level concepts better than the real laboratory and the control group because it allows students to visualise the molecular processes involved in the chemical reactions.

In this experimental study, the teaching method is the independent variable, that is, the proposed educational system with the Leap Motion controller, the proposed educational system with the mouse, the real laboratory, or nothing (the control group) in support of the theoretical lessons. The learning achievement is the dependent variable of this experimental study. The main effects of the conditions (the proposed educational system with the Leap Motion controller, the proposed educational system with the mouse, the real laboratory, and nothing) on the dependent variable were compared. Moreover, post-hoc comparisons were conducted to indicate the significant differences in the learning achievement between the classes, where the significance level was 5% ($p < 0.05$).

7.6 Results

This section reports the results for each experiment and derives the learning indications. The score for each student was the sum of the answers to the multiple-choice questions on the tests, with correct answers scoring 1 and incorrect answers scoring 0. No penalty was given for wrong answers or for answering ‘I don’t know’.

The results for each experiment comprise three parts. First, the differences between the learning achievements of the students in general by class from the pretest and posttest were explored. Then, the changes in learning achievement for questions related to knowledge of the macroscopic view of the chemistry lesson in the posttest were studied. Finally, the changes in the learning achievement were analysed for the questions related to knowledge of the microscopic view of the lesson in the posttest.

7.6.1 Experiment 1 results

a. Learning achievement

In the pretest for Class 1, the mean test score was 0.58, and the standard deviation was 0.703. The corresponding values were 0.43 and 0.79 for Class 2, 0.59 and 0.907 for Class 3, and 0.53 and 0.819 for Class 4, respectively. Table 7-2 illustrates the results without applying the lesson (Class 1), the real laboratory (Class 2), the proposed educational system with the Leap Motion controller (Class 3), and the proposed educational system with the mouse (Class 4). As depicted in Figure 7-6, no significant differences were found between these four classes in the pretest (p = .881) according to the independent ANOVA test results (see Table 7-3). Therefore, students in these four classes had similar prior knowledge before the start of the first experiment.

While the pretest results confirmed no differences in prior knowledge between the four classes, the learning achievement of these classes was studied in the posttest to identify the effects of the proposed educational system. In the posttest after the lesson, the mean was 3.31, and the standard deviation was 1.123 for Class 1. Equivalent scores were obtained for Class 2 at 3.71 and 1.084, Class 3 at 4.10 and 0.817, and Class 4 at 3.9 and 0.96, respectively (see Table 7-2). The one-way ANOVA identified significant differences between the four conditions in the posttest (F (3, 109) = 3.135, p = .028). Table 7-3 lists the effects and multiple comparisons of the four static conditions. A significant difference between the learning achievements of Classes 1 and 3 (p = .023) is indicated by the post-hoc comparisons using the Bonferroni correction; however, no significant differences were found between the conditions of Classes 1 and 2 (p = .826), Classes 1 and 4 (p = .173), Classes 2 and 3 (p = .865), Classes 2 and 4 (p = 1.000) or Classes 3 and 4 (p = 1.000; see Figure 7-7).

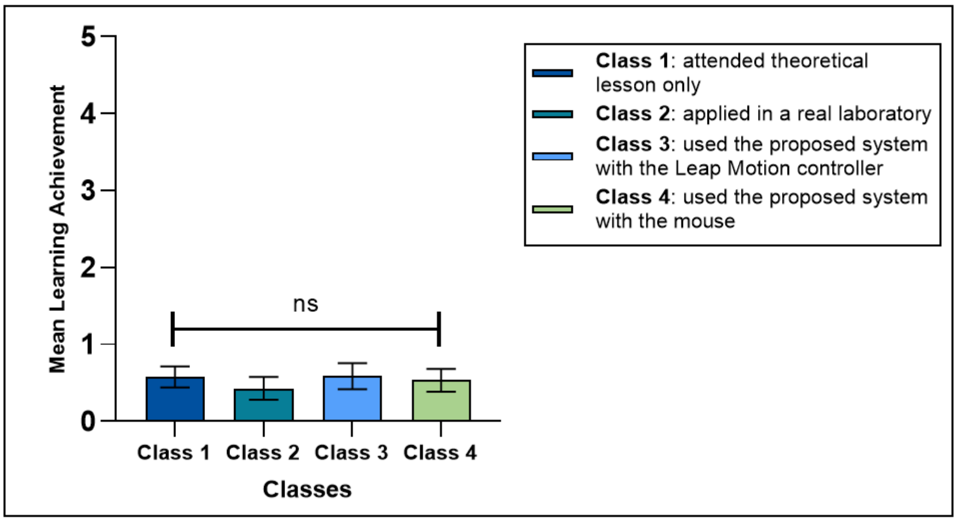


Figure 7-6 Pretest results of all four classes for students' learning achievements in the first chemistry experiment. Asterisks denote significance levels: not significant (ns) p > 0.05, * p < 0.05, ** p < 0.01, and *** p < 0.001.

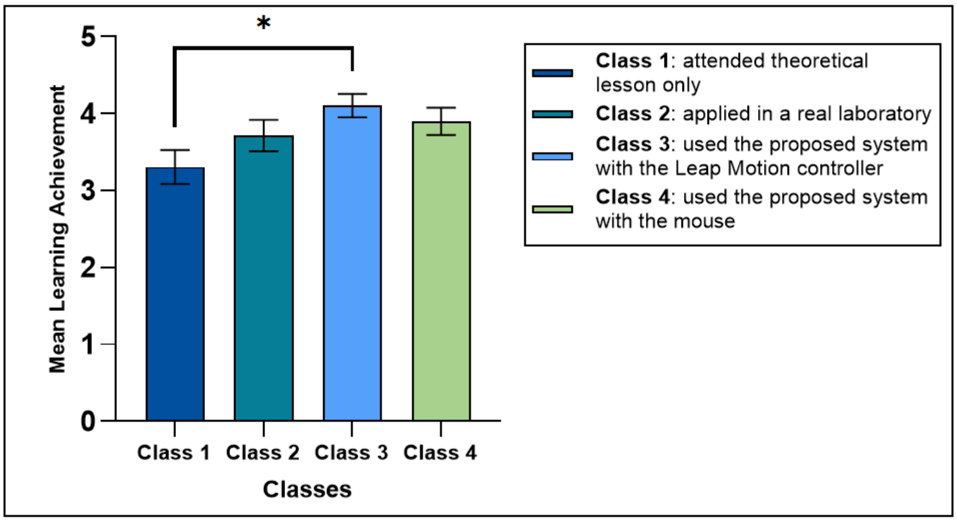


Figure 7-7 Posttest results of all four classes for students' learning achievements in the first chemistry experiment. Asterisks denote significance levels: not significant (ns) $p > 0.05$, * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

b. Learning achievement in the macroscopic view

In the first lesson test, three questions targeted the participants' understanding of the experimental concepts and knowledge of the macroscopic view, as reported by the chemistry teachers. The results of these questions in the posttest were examined to analyse the learning achievement of the students regarding their knowledge of the macroscopic view of the chemistry lesson. The mean was 2.42, and the standard deviation was 0.703 for Class 1, with equivalent values of 2.54 and 0.576 for Class 2, 2.38 and 0.622 for Class 3 and 2.30 and 0.651 for Class 4, respectively (Table 7-2). As illustrated in Figure 7-8, the results indicated no significant differences between classes (F (3, 109) = 0.684, p = .564; see Table 7-3).

c. Learning achievement in the microscopic view

The learning achievement of participants for questions relating to their knowledge of the microscopic view of the chemistry lesson was examined by analysing the results of two questions in the posttest. According to the chemistry teachers, these questions targeted student understanding of the experimental concepts and information about the microscopic view of the lesson. The means and standard deviations for learning achievement in the microscopic view of the posttest are listed in Table 7-2. The one-way ANOVA identified significant differences (F (3, 109) = 9.033, p = .000). As depicted in Figure 7-9, a post-hoc test (Bonferroni) was conducted and indicated significant differences in the test scores between Classes 1 and 3 (p = .000), Classes 1 and 4 (p = .001) and Classes 2 and 3 (p = .017). No significant differences were found between Classes 1 and 2 (p = .678), Classes 2 and 4 (p = .116) or Classes 3 and 4 (p = 1.000; see Table 7-3).

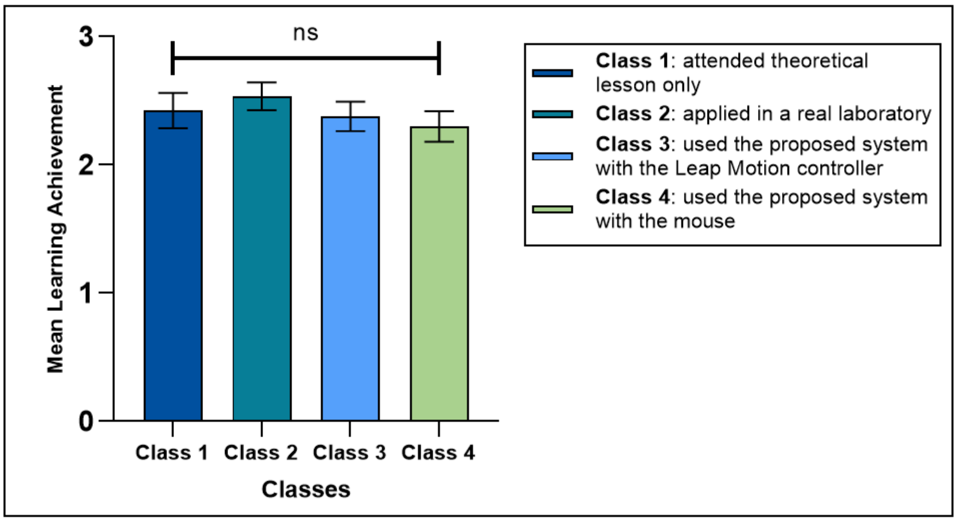


Figure 7-8 Posttest results of all four classes for students' learning achievements in the macroscopic view of the first chemistry experiment. Asterisks denote significance levels: not significant (ns) p > 0.05, * p < 0.05, ** p < 0.01, and *** p < 0.001.

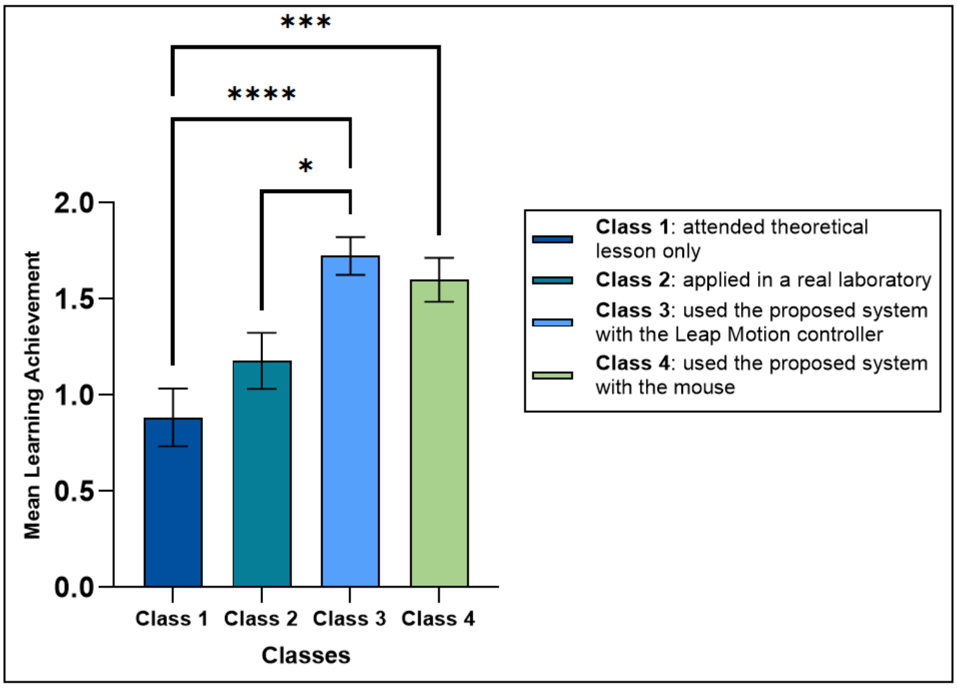


Figure 7-9 Posttest results of all four classes for students' learning achievements in the microscopic view of the first chemistry experiment. Asterisks denote significance levels: not significant (ns) p > 0.05, * p < 0.05, ** p < 0.01, *** p < 0.001, and **** p < 0.0001.

d. 'I do not know' responses

In the pretest for Class 1, the mean was 1.42, and the standard deviation was 1.501. The equivalent values were 1.21 and 1.813 for Class 2, 1.34 and 1.717 for Class 3 and 1.37 and 1.564 for Class 4, respectively. Table 7-4 lists the results of the four classes for the students' 'I do not know' responses. No significant differences exist between these four classes in the pretest (*p* = .972) according to the independent ANOVA test results (see Table 7-5 and Figure 7-10).

In the posttest for Class 1, the mean was 0.38, and the standard deviation was 0.571. These values were 0.21 and 0.418 for Class 2, 0.14 and 0.351 for Class 3 and 0.10 and 0.305 for Class 4, respectively. Table 7-4 presents the results of the four classes for the students' 'I do not know' responses. As presented in Figure 7-11, no significant differences were found between these four classes in the posttest (*p* = .064; see Table 7-5).

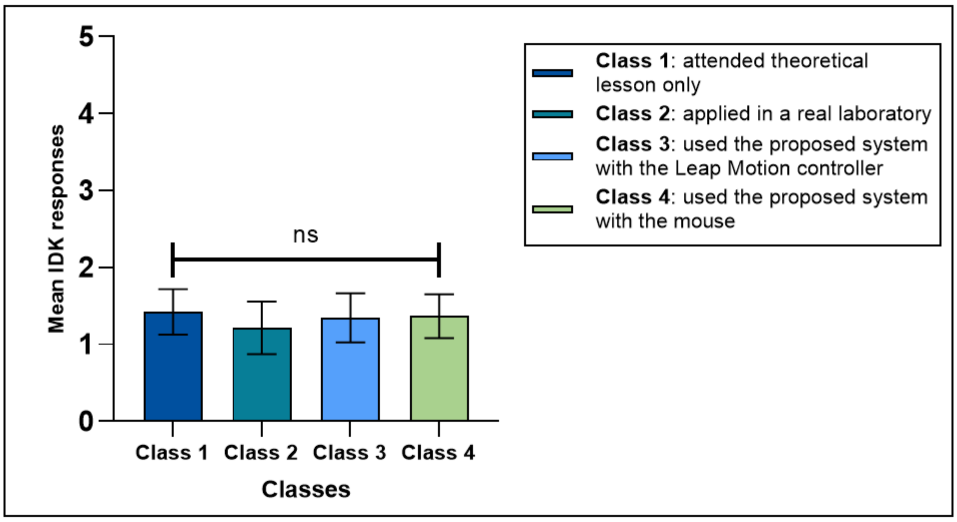


Figure 7-10 Pretest results of all four classes for students' 'I do not know' (IDK) responses in the first chemistry experiment. Asterisks denote significance levels: not significant (ns) p > 0.05, * p < 0.05, ** p < 0.01, *** p < 0.001, and **** p < 0.0001.

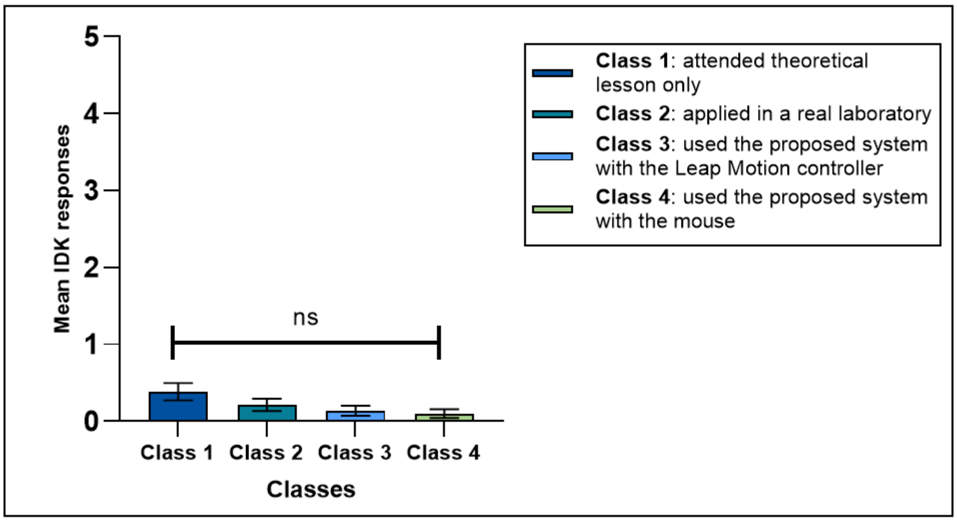


Figure 7-11 Posttest results of all four classes for students' 'I do not know' (IDK) responses in the first chemistry experiment. Asterisks denote significance levels: not significant (ns) p > 0.05, * p < 0.05, ** p < 0.01, *** p < 0.001, and **** p < 0.0001.

Study Case	Static Condition	N	Mean	Std. Deviation	Std. Error
Pretest	Class 1	26	0.580	0.703	0.138
	Class 2	28	0.430	0.790	0.149
	Class 3	29	0.590	0.907	0.168
	Class 4	30	0.530	0.819	0.150
Posttest	Class 1	26	3.310	1.123	0.220
	Class 2	28	3.710	1.084	0.205
	Class 3	29	4.100	0.817	0.152
	Class 4	30	3.900	0.960	0.175
Macroscopic view of the posttest	Class 1	26	2.420	0.703	0.138
	Class 2	28	2.540	0.576	0.109
	Class 3	29	2.380	0.622	0.115
	Class 4	30	2.300	0.651	0.119
Microscopic view of the posttest	Class 1	26	0.880	0.766	0.150
	Class 2	28	1.180	0.772	0.146
	Class 3	29	1.720	0.528	0.098
	Class 4	30	1.600	0.621	0.113

Table 7-2 Means, standard deviations and standard errors of all four classes for students' learning achievements in each study case of the first chemistry experiment.

Study Case	Effects	Df	F	Sig.
Pretest	Condition	3, 109	0.222	0.881
	Class 1 v Class 2			
	Class 1 v Class 3			
	Class 1 v Class 4			
	Class 2 v Class 3			
	Class 2 v Class 4			
	Class 3 v Class 4			
Posttest	Condition	3, 109	3.135	.028*
	Class 1 v Class 2			.826
	Class 1 v Class 3			.023*
	Class 1 v Class 4			.173
	Class 2 v Class 3			.865
	Class 2 v Class 4			1.000
	Class 3 v Class 4			1.000
Macroscopic view of the posttest	Condition	3, 109	.684	.564
	Class 1 v Class 2			
	Class 1 v Class 3			
	Class 1 v Class 4			
	Class 2 v Class 3			
	Class 2 v Class 4			
	Class 3 v Class 4			
Microscopic view of the posttest	Condition	3, 109	9.033	0.000*
	Class 1 v Class 2			.678
	Class 1 v Class 3			.000*
	Class 1 v Class 4			.001*
	Class 2 v Class 3			.017*
	Class 2 v Class 4			.116
	Class 3 v Class 4			1.000

Table 7-3 Main effects and pairwise comparisons of students' learning achievements for all study cases of the first chemistry experiment. * Denotes statistical significance.

Study Case	Static Condition	N	Mean	Std. Deviation	Std. Error
IDK pretest	Class 1	26	1.42	1.501	0.294
	Class 2	28	1.21	1.813	0.343
	Class 3	29	1.34	1.717	0.319
	Class 4	30	1.37	1.564	0.286
IDK posttest	Class 1	26	0.38	0.571	0.112
	Class 2	28	0.21	0.418	0.079
	Class 3	29	0.14	0.351	0.065
	Class 4	30	0.10	0.305	0.056

Table 7-4 Means, standard deviations and standard errors of all four classes for students' 'I do not know' (IDK) responses in each study case of the first chemistry experiment.

Study Case	Effects	Df	F	Sig.
IDK pretest		3, 109	.078	.972
IDK posttest		3, 109	2.488	.064

Table 7-5 Main effects of the students' 'I do not know' (IDK) responses for all study cases of the first chemistry experiment.

7.6.2 Experiment 2 results

a. Learning achievement

Table 7-6 illustrates the results of the four classes in the pretest of the second lesson. The mean was 1.46, and the standard deviation was 1.272 for Class 1. The means and standard deviations were 1.39 and 1.315 for Class 2, 1.24 and 1.154 for Class 3 and 1.73 and 1.311 for Class 4, respectively.

According to the independent ANOVA test results, no significant differences exist between these four classes on the pretest (p = .506; see Table 7-7 and Figure 7-12). Therefore, the prior knowledge of students was similar in these four classes before the start of Experiment 2. The learning achievements of these classes were studied in the posttest to identify the influences of the proposed educational system and laboratory.

Table 7-6 displays the results of the four conditions in the posttest of Experiment 2. The one-way ANOVA identified significant differences for the four conditions in the posttest (F (3, 109) = 9.805, p = .000). Table 7-7 presents both the effects and multiple comparisons of the four static conditions. As depicted in Figure 7-13, post-hoc comparisons using the Bonferroni correction indicate significant differences for the learning achievements between Classes 1 and 4 (p = .000), Classes 2 and 4 (p = .000) and Classes 3 and 4 (p = .019). In contrast, no significant differences were found between Classes 1 and 2 (p = 1.000), Classes 1 and 3 (p = .290) or Classes 2 and 3 (p = 1.000).

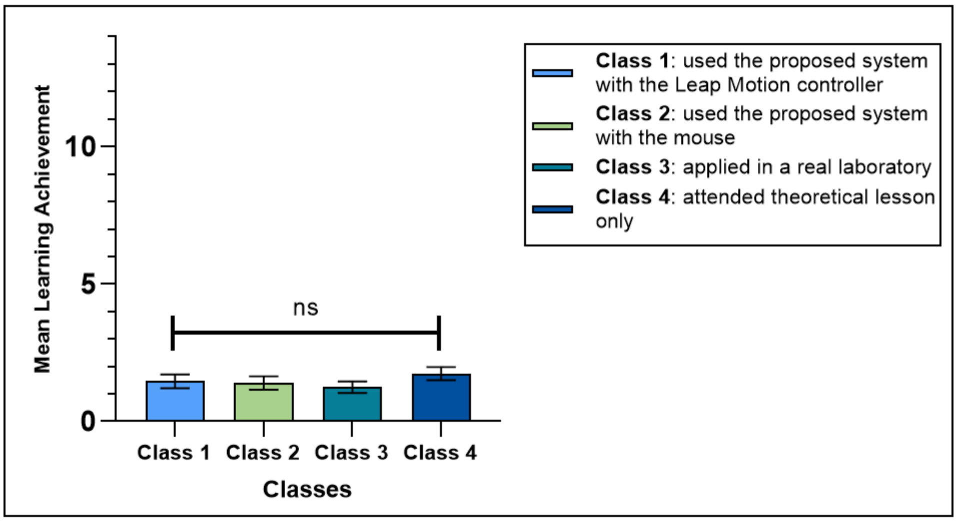


Figure 7-12 Pretest results of all four classes for students' learning achievements in the second chemistry experiment. Asterisks denote significance levels: not significant (ns) p > 0.05, * p < 0.05, ** p < 0.01, and *** p < 0.001.

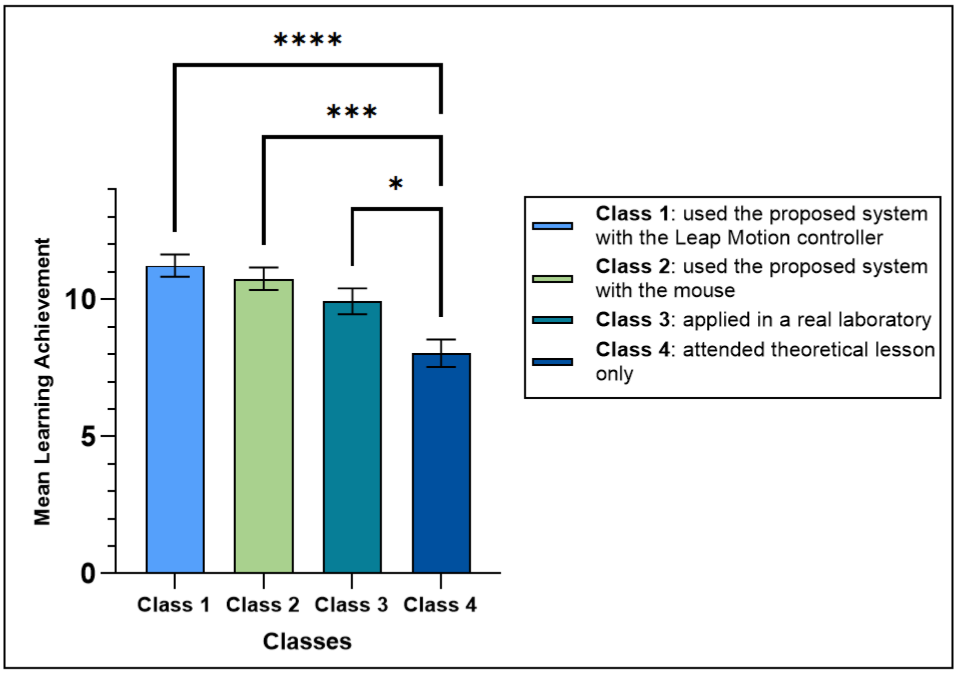


Figure 7-13 Posttest results of all four classes for students' learning achievements in the second chemistry experiment. Asterisks denote significance levels: not significant (ns) p > 0.05, * p < 0.05, ** p < 0.01, *** p < 0.001, and **** p < 0.0001.

b. Learning achievement in the macroscopic view

The learning achievement for the questions relating to knowledge of the macroscopic view of the chemistry lesson was examined by analysing the results of the first four questions in the posttest. The chemistry teachers stated that these questions targeted student understanding of the experimental concepts and information about the macroscopic view of the lesson. The means and standard errors for the learning achievement in the macroscopic view of the posttest are displayed in Table 7-6. As illustrated in Figure 7-14, the results indicated no significant differences between conditions (F (3, 109) = 1.767, p = .158; see Table 7-7).

c. Learning achievement in the microscopic view

The results of Questions 5 to 14 in the posttest were studied. According to the chemistry teachers, these questions targeted student understanding of the microscopic concepts and models of the chemistry lesson. The means and standard errors for learning achievement in the microscopic view of the posttest are displayed in Table 7-6. The one-way ANOVA identified significant differences (F (3, 109) = 13.108, p = .000), and the subsequent post-hoc test (Bonferroni) indicated significant differences in test scores between Classes 1 and 3 (p = .010), Classes 1 and 4 (p = .000) and Classes 2 and 4 (p = .000). No significant differences exist between conditions for Classes 1 and 2 (p = 1.000), Classes 2 and 3 (p = .090) or Classes 3 and 4 (p = .106; see Table 7-7 and Figure 7-15).

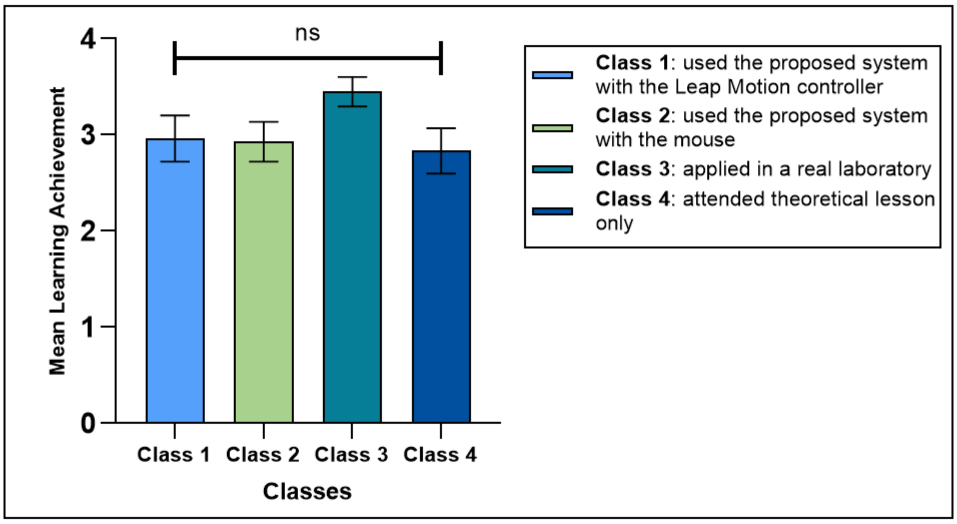


Figure 7-14 Posttest results of all four classes for students' learning achievements in the macroscopic view of the second chemistry experiment. Asterisks denote significance levels: not significant (ns) p > 0.05, * p < 0.05, ** p < 0.01, and *** p < 0.001.

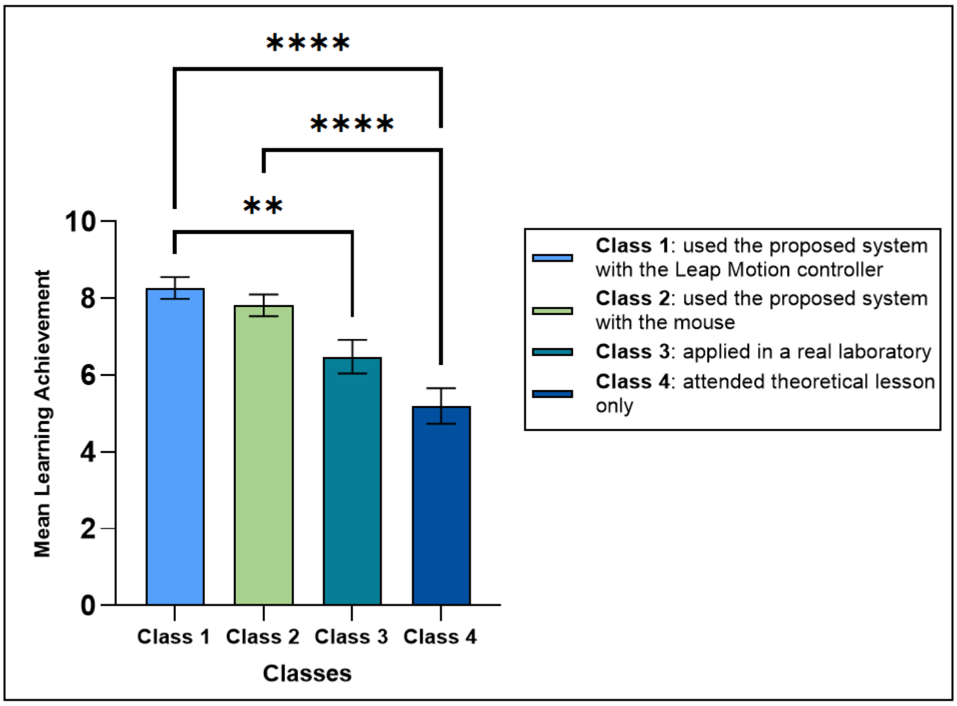


Figure 7-15 Posttest results of all four classes for students' learning achievements in the microscopic view of the second chemistry experiment. Asterisks denote significance levels: not significant (ns) p > 0.05, * p < 0.05, ** p < 0.01, *** p < 0.001, and **** p < 0.0001.

d. 'I do not know' responses

In the pretest for Class 1, the mean was 2.69, and the standard deviation was 5.206. These respective values were 2.36 and 4.466 for Class 2, 2.21 and 3.922 for Class 3, and 2.60 and 4.724 for Class 4. Table 7-8 illustrates the results of the four classes for the students' 'I do not know' responses. No significant differences exist between the four classes in the pretest (p = .978; see Table 7-9 and Figure 7-16).

In the posttest for Class 1, the mean was 0.23, and the standard deviation was 0.652. These values were 0.25 and 0.441 for Class 2, 0.31 and 0.604 for Class 3 and 0.50 and 1.225 for Class 4, respectively. Table 7-8 illustrates the results of the four classes for the students' 'I do not know' responses. As presented in Figure 7-17, no significant differences exist between the four classes in the posttest (p = .563; see Table 7-9).

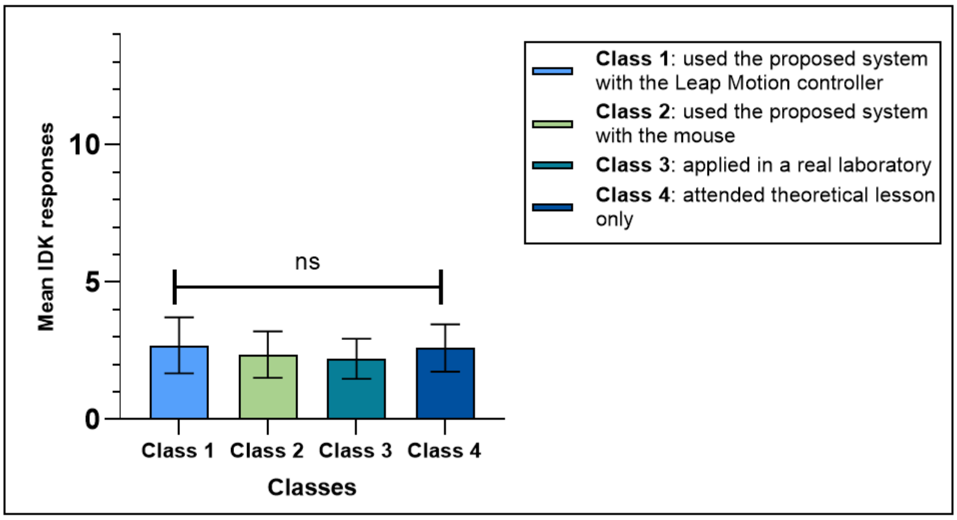


Figure 7-16 Pretest results of all four classes for students' 'I do not know' (IDK) responses in the second chemistry experiment. Asterisks denote significance levels: not significant (ns) p > 0.05, * p < 0.05, ** p < 0.01, *** p < 0.001, and **** p < 0.0001.

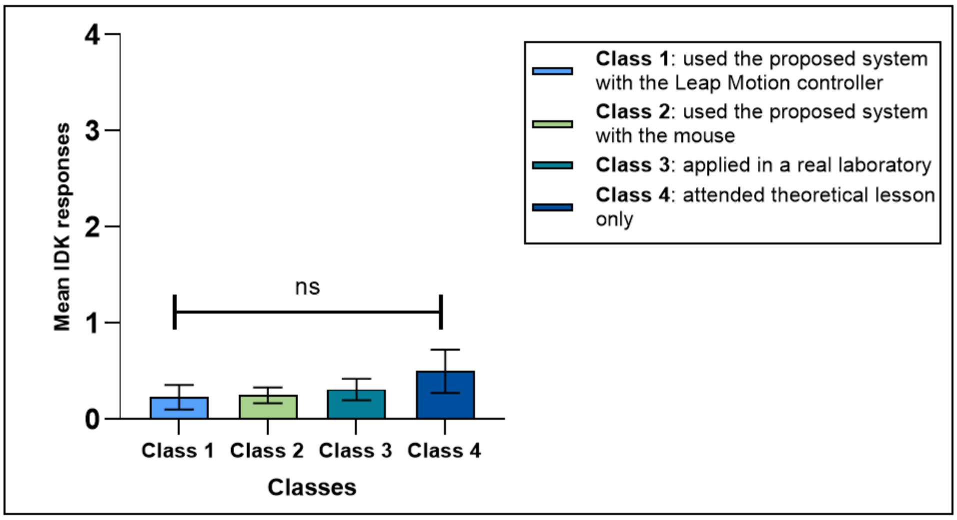


Figure 7-17 Posttest results of all four classes for students' 'I do not know' (IDK) responses in the second chemistry experiment. Asterisks denote significance levels: not significant (ns) p > 0.05, * p < 0.05, ** p < 0.01, *** p < 0.001, and **** p < 0.0001.

Study Case	Static Condition	N	Mean	Std. Deviation	Std. Error
Pretest	Class 1	26	1.46	1.272	0.249
	Class 2	28	1.39	1.315	0.248
	Class 3	29	1.24	1.154	0.214
	Class 4	30	1.73	1.311	0.239
Posttest	Class 1	26	11.23	2.103	.413
	Class 2	28	10.75	2.137	.404
	Class 3	29	9.93	2.534	.471
	Class 4	30	8.03	2.748	.502
Macroscopic view of the posttest	Class 1	26	2.96	1.216	.238
	Class 2	28	2.93	1.086	.205
	Class 3	29	3.45	.827	.154
	Class 4	30	2.83	1.289	.235
Microscopic view of the posttest	Class 1	26	8.27	1.458	.286
	Class 2	28	7.82	1.517	.287
	Class 3	29	6.48	2.370	.440
	Class 4	30	5.20	2.511	.458

Table 7-6 Means, standard deviations and standard errors of all four classes for students' learning achievements in each study case of the second chemistry experiment.

Study Case	Effects	Df	F	Sig.
Pretest	Condition	3, 109	.782	.506
	Class 1 v Class 2			
	Class 1 v Class 3			
	Class 1 v Class 4			
	Class 2 v Class 3			
	Class 2 v Class 4			
	Class 3 v Class 4			
Posttest	Condition	3, 109	9.805	0.000*
	Class 1 v Class 2			1.000
	Class 1 v Class 3			.290
	Class 1 v Class 4			.000*
	Class 2 v Class 3			1.000
	Class 2 v Class 4			.000*
	Class 3 v Class 4			.019*
Macroscopic view of the posttest	Condition	3, 109	1.767	.158
	Class 1 v Class 2			
	Class 1 v Class 3			
	Class 1 v Class 4			
	Class 2 v Class 3			
	Class 2 v Class 4			
	Class 3 v Class 4			
Microscopic view of the posttest	Condition	3, 109	13.108	0.000*
	Class 1 v Class 2			1.000
	Class 1 v Class 3			.010*
	Class 1 v Class 4			.000*
	Class 2 v Class 3			.090
	Class 2 v Class 4			.000*
	Class 3 v Class 4			.106

Table 7-7 Main effects and pairwise comparisons of students' learning achievements for all study cases of the second chemistry experiment. * Denotes statistical significance.

Study Case	Static Condition	N	Mean	Std. Deviation	Std. Error
IDK pretest	Class 1	26	2.69	5.206	1.021
	Class 2	28	2.36	4.466	0.844
	Class 3	29	2.21	3.922	0.728
	Class 4	30	2.60	4.724	0.863
IDK posttest	Class 1	26	0.23	0.652	0.128
	Class 2	28	0.25	0.441	0.083
	Class 3	29	0.31	0.604	0.112
	Class 4	30	0.50	1.225	0.224

Table 7-8 Means, standard deviations and standard errors of all four classes for the students' 'I do not know' (IDK) responses in each study case of the second chemistry experiment.

Study Case	Effects	Df	F	Sig.
IDK pretest		3, 109	.066	.978
IDK posttest		3, 109	.686	.563

Table 7-9 Main effects of the students' 'I do not know' (IDK) responses for all study cases of the second chemistry experiment.

7.7 Discussion

This experimental study aims to evaluate the ability of the proposed educational system to provide better learning of general chemistry and microscopic-level chemistry concepts compared with traditional methods, including real laboratory and theory-only approaches.

First, the results indicated no significant differences between the four classes on the pretest. Thus, no prior knowledge differences were found between the four classes before starting the experimental study.

Moreover, the results demonstrate a significant difference in learning achievement between the proposed system and the theory-only approach. In Experiment 1, a significant difference exists in the learning achievements (p = .023) between the proposed educational system using the Leap Motion controller and the theory-only approach. In Experiment 2, a significant difference was found in the learning achievements (p = .000) between the proposed educational system using the Leap Motion controller and the theory-only approach. In addition, a significant difference exists in the learning achievements (p = .000) between the proposed educational system using the mouse and the theory-only approach.

However, no significant difference was found in the learning achievement between the proposed educational system and traditional laboratory approach. In Experiment 1, no significant difference exists in the learning achievements (p = .865) between the proposed educational system using the Leap Motion controller and the real laboratory approach. Moreover, no significant difference exists in the learning achievements (p = 1.000) between the proposed educational system using the mouse and the real laboratory approach. In Experiment 2, no significant difference was found in the learning achievements (p = .290) between the proposed educational system using the Leap Motion controller and the real laboratory approach. Further, no significant difference exists in the learning achievements (p = 1.000) between the proposed educational system using the mouse and the real laboratory approach.

Therefore, the results support the first hypothesis that the proposed system and a real laboratory are comparable. Students using the proposed system could, therefore, better understand a chemistry lesson than those just given the theoretical lesson without applying the experiment. In contrast, the students who applied the theory using the proposed system would have the same learning achievement as the students conducting the experiment in the real laboratory. These results imply that the proposed system has the same effect as a real laboratory and could be used as an alternative to a real chemistry laboratory if one is unavailable, for example, in the case of distance education, where materials are unavailable or have a high risk or where the experiment is of long duration.

A critical study result is that significant effects were found for learning achievement at the microscopic level in the posttest in both experiments. Accordingly, a significant difference exists in learning achievements between the proposed educational system, whether using the Leap Motion controller or the mouse, and the theory-only approach. In Experiment 1, a significant difference exists in the learning achievements at the microscopic level (p = .000) between the proposed system using the Leap Motion controller and the theory-only approach. In addition, a significant difference was found in the learning achievements at the microscopic level (p = .001) between the proposed system using the mouse and the theory-only approach. In Experiment 2, a significant difference exists in the learning achievements at the microscopic level (p = .000) between the proposed system using the Leap Motion controller and the theory-only approach. Moreover, a significant difference exists in the learning achievements at the microscopic level (p = .000) between the proposed system using the mouse and the theory-only approach.

Further, the results reveal a significant difference in learning achievement between the proposed system with the Leap Motion controller and the traditional real laboratory approach. In Experiment 1, a significant difference exists in the learning achievements at the microscopic level (p = .017) between the proposed system using the Leap Motion controller and the real laboratory approach. In Experiment 2, a significant difference was found in the learning achievements at the microscopic level (p = .010) between the proposed system using the Leap Motion controller and the real laboratory approach.

Additionally, no significant difference exists in learning achievement between the traditional laboratory approach and the theory-only approach. In Experiment 1, no significant difference exists in the learning achievements at the microscopic level (p = .678) between the real laboratory approach and the theory-only approach. In Experiment 2, no significant difference exists in the learning achievements at the microscopic level (p = .106) between the real laboratory approach and the theory-only approach.

Therefore, the results support the second hypothesis that students could better understand the microscopic view of a chemistry lesson when using the proposed system with the Leap Motion controller than when conducting the experiment in a real laboratory or just attending a theoretical lesson without applying the experiment. Students better understood the microscopic view of a chemistry lesson using the proposed system with the mouse than when just given the theoretical lesson without applying the experiment. These results imply that the proposed system improves the teaching of microscopic knowledge of chemistry, so students learn this better when using the proposed educational system. In addition, those using the real laboratory have the same learning outcomes as those attending a theoretical lesson only.

To conclude, the main objective of this system is the demonstration of concepts and experiments in practice using molecular visualisation to interpret the results and explain the microscopic causes and changes leading to them. This critical finding confirms that the system increases student understanding of the microscopic view of chemistry concepts. Additionally, no significant differences were found in the mean of 'I do not know' responses between the classes with students who used the proposed system and those whose students using traditional methods. However, the means of the proposed educational system in two test cases in Tables 7-4 and 7-8 were smaller than those using the real laboratory and those only attending the theoretical lesson in the two test cases.

7.8 Chapter Summary

This chapter examined the proposed educational system through an experimental study on four secondary school classes, based on a pretest and posttest experimental procedure to evaluate student learning achievement before and after attending two chemistry lessons.

This study found a significant difference in learning achievement between the class that had the theoretical lesson and applied it using the proposed system and the class that had the theoretical lesson only. These results support the first hypothesis that the proposed educational system is comparable with the traditional laboratory teaching approach on student learning achievement, which indicates that using experimental learning favours the acquisition of chemistry concepts.

Moreover, significant differences were found between classes at the microscopic level in the posttest. A significant difference exists in learning achievements between the class that had the theoretical lesson and applied it using the proposed system, whether using the Leap Motion controller or mouse, and the class with only the theoretical lesson. A significant difference exists in learning achievements between the class that had the theoretical lesson and applied it using the proposed system with the Leap Motion controller and the class that had the theoretical lesson and applied it in the real chemistry laboratory. These results support the second hypothesis that when the students use the proposed educational system, they learn and understand the microscopic-level concepts better than when they are taught using the real laboratory or a theoretical lesson only. This finding indicates that the proposed system improves learning the microscopic-level concepts by allowing students to visualise and interact with the molecular structures and chemical reaction processes.

Chapter 8. FINDINGS AND DISCUSSION

8.1 Introduction

This chapter aims to analyse the performance of the proposed educational system designed for secondary school students using gestures to interact with the system. Therefore, it discusses and evaluates the findings of this research as they relate to the hypothesis. The research hypothesis is that using gesture-based technology and combining simulation and molecular visualisation technologies in education will improve the teaching method and knowledge acquisition. The effects of the system on the students' education and acquisition of knowledge are analysed and explained based on the experiment results. The experiment results with the system are described and discussed, including the findings of the interview study, usability testing and experimental study. Then, the research hypothesis and findings of the present study are assessed and discussed.

8.2 Findings of the Research Experiment

The developed educational system integrates both views: the macroscopic view of the chemistry laboratory and the microscopic view of the molecular structure, using the Leap Motion controller for greater convenience and practicality for users. After developing this educational system, it was examined using several methods to evaluate its effectiveness in achieving the research objectives (i.e. the system's effectiveness in developing science education and teaching molecular chemistry concepts at the secondary school level). The research experiment comprises several research methods used to achieve the objectives of this research and validate the research hypothesis in the form of interviews, usability testing and an experimental study. In the following sections, the findings of these three research methods are discussed, and the research hypothesis is assessed.

8.2.1 Findings of the interview study and discussion

The role of the teacher in the educational process is vital; thus, this role was crucial in testing the proposed educational system and evaluating its abilities. In addition, it is beneficial to include the teachers when designing an educational system for school students as they have more insight on teaching the selected subject. Consequently, the responses from the interview study provided considerable insight, despite the relatively few users. In addition, this study provides knowledge that can assist in accurately anticipating users' concerns about new technologies to support education and the learning process. The results of the teachers' interviews are detailed in Sections 6.2.2 and 6.2.3.

The teachers' interview results indicated that no educational systems are currently designed for secondary schools that use gesture-based technology and merge virtual laboratory simulation and molecule virtualisation. The five interviewed teachers generally liked the educational system and found it easy to use, helpful and realistic in terms of the simulation. The idea of combining the two different views (macroscopic and microscopic) was favoured by all five teachers. Thus, the proposed educational system integrates numerous benefits in a virtual learning environment, delivered through an immersive 3D graphical interface and a new intuitive interaction method, the Leap Motion controller, which simulates hand and finger movements by tracking. The results confirmed that this educational system integrating gesture-based technology presents an opportunity to combine practical experiences with molecular explanations to improve understanding and interrelate theory and chemistry concepts, as claimed by the teachers. This system can solve many of the complexities and obstacles that challenge chemistry teachers continuously, such as increasing class sizes, shortage of time and lack of materials, according to the five teachers.

Consequently, the results from the interviews support the research hypothesis that the proposed educational system, using gesture-based technology and integrating simulation and molecular visualisation technologies, can improve chemistry teaching. The system offers benefits in providing a better understanding of microscopic-level chemistry concepts compared to theoretical learning. Additionally, these results confirm that the proposed system can help solve the significant teaching difficulties regularly faced by teachers. Thus, integrating these technologies, simulation and molecular visualisation, with gesture-based technology supports the research aim and has significant advantages for education. This outcome demonstrates the ability to improve education through technology and overcome teaching and learning obstacles.

8.2.2 Findings of the usability testing and discussion

The usability of the system interface and information must be evaluated, as it was designed for a range of users. A large sample of users was recruited voluntarily to guarantee the stability of the results and ensure the selection of various users. Usability testing reveals users' reactions when they test the system for the first time regarding gesture-based technology and other educational technologies. Furthermore, this study helps understand the users' evaluation of the system's usability and flexibility. The results of the usability testing are presented in Tables 6-3, 6-5 and 6-6 in Chapter 6.

The usability requirements are supported by the results obtained through testing, which indicated that the system is easy to use without requiring extensive training. Furthermore, the results confirm that the system is self-explanatory and intuitive so that a user can complete the experiment tasks without needing help. The system usability testing results demonstrate that the provided information is easy to understand and that the user's ability to comprehend the experiment tasks and scenarios is greatly improved through the system.

The usability testing also found that, although users felt comfortable using the mouse because it is a familiar input device, the Leap Motion controller was more straightforward to use than the mouse. Additionally, users liked the system interface with the Leap Motion controller and expressed interest in using the system again, more than the users who interacted with the system through the mouse.

These results support the research hypothesis that the proposed system and gesture-based technology could be used in chemistry education to make teaching more effective and improve learning achievement. From these results, students can easily use this system without long-term training, perform the experiment tasks on the first attempt with ease, and find the provided information comprehensible. Accordingly, they can use the Leap Motion controller, which simulates hand and finger movements, to interact with the interface simply. Therefore, gesture-based technology and combining simulation and molecular visualisation technologies have positive effects on education.

8.2.3 Findings of the experimental study and discussion

An experimental study was conducted to study the effect of the developed educational system on the learning achievement in secondary school. The experiment comprised pretests and posttests to evaluate students' academic achievement in four secondary school classes before and after attending chemistry lessons on two different subjects. Each class represented a distinct set of conditions. The results of the first lesson are listed in Table 7- 3 in Chapter 7, which includes four case studies, the pretest, posttest, macroscopic view of the posttest and microscopic view of the posttest. Moreover, the results of the second lesson are presented in Table 7-7 in Chapter 7, which includes the same four case studies.

In both lessons, no significant differences were noted between the four groups on the pretest, meaning no prior knowledge differences were found between the four classes. In contrast, a significant effect was found on information retention for the four classes in the posttests in both lessons, as follows:

- The post-hoc comparisons indicated that the mean score for the class with the theoretical lesson applied using the proposed system was significantly different from the class that had the theoretical lesson only.
- In addition, no significant difference exists in learning achievements between the class that had the theoretical lesson applied using the proposed system and the class that had the theoretical lesson applied in the real chemistry laboratory.

Finally, significant effects were found for learning achievements at the microscopic level, shown in the posttest for both lessons and detailed as follows:

- Significant differences exist in the mean test scores for the class that had the theoretical lesson applied using the proposed system and the Leap Motion controller compared with the classes with the theoretical lesson applied in the real chemistry laboratory and that had only the theoretical lesson.
- Significant differences exist between the mean test scores for the class with the theoretical lesson applied using the proposed system and the mouse and those in the class with only the theoretical lesson.
- However, no significant difference exists in learning achievements between the class that had the theoretical lesson applied in the real chemistry laboratory and the class with only the theoretical lesson.

These results indicate that students acquired the same knowledge when using the proposed educational system as when they used the real laboratory and had better results than when they received the theoretical lesson only. Moreover, these results demonstrate that acquired knowledge at the microscopic level is better for students who used the proposed educational system with the Leap Motion controller than those who used the real laboratory or had only the theoretical lesson.

8.3 Discussion

As previously stated, the experimental study aims to test two hypotheses. The first hypothesis relates to active learning processes and whether the proposed educational system has a facilitating effect on learning achievement comparable to the real laboratory method and is better than the theory-only method. The second hypothesis investigates whether students who use the proposed educational system understand microscopic-level chemistry concepts better than those who use traditional methods, the real laboratory or theoretical teaching alone with no active learning phase.

Concerning the first hypothesis, the results revealed that the proposed educational system is better than the theoretical approach because the learning achievement of the class with the theoretical lesson applied using the proposed system was better than the learning achievement of the class with the theoretical lesson only in the experimental study in the two lessons. According to the results, students understand a chemistry lesson better when using the system than when just given the theoretical lesson without physically performing the experiment.

Moreover, no difference exists between the educational system and real laboratory conditions, whether the system is controlled through the Leap Motion controller or mouse. It appears that the students who applied the theory learnt in the lesson using the proposed system have the same learning achievement as the students who applied the lesson in the real laboratory. These results demonstrated that the proposed educational system and real laboratory are comparable. Therefore, the proposed system may be a valid alternative for real-world experiments in chemistry laboratories. However, despite the significant difference, other factors or limitations of the present study may have influenced the results, as follows:

1. The participants in this study come from one grade at one school, which could affect the study results. Therefore, a study with a more diverse sample may provide a better prediction of the influences of the system.
2. The study used an exam prepared by the chemistry teachers to assess learning achievement, which could be inappropriate. The researcher observed that the exam was slightly unbalanced in its coverage of macroscopic and microscopic information. Particularly for the second lesson, the majority of questions covered the microscopic level, whereas few covered the macroscopic level. In addition, several questions were focused on similar concepts, whereas other concepts were neglected. Thus, the results may differ if a researcher prepared the evaluation exam.
3. Students were familiar with the real laboratory and had used it many times before for different lessons in different years of their school lives. In contrast, these students were using the proposed educational system and the Leap Motion controller for the first time. This lack of familiarity may have distracted their attention and reduced their focus on the lesson, which would affect the study outcome. This outcome is relevant

to the present study in that several researchers have noted that the use of digital devices in a classroom environment can distract students (P. Lam & Tong, 2012).

4. In addition, some researchers have found that students do not feel that systems simulating virtual laboratories provide a realistic laboratory experience, which could affect the results (Corter et al., 2007; Sauter et al., 2013). These differences between students in the studies could influence the expected results.

As reported, no significant difference exists between the learning achieved using the proposed educational system and that achieved in the real laboratory. In other words, the proposed educational system can take the place of real-world experiments. Interestingly, the mean scores of the proposed educational system in the two test cases, presented in Tables 7-2 and 7-6 in Chapter 7, were higher than those in the real laboratory and those with no practical experience in the two test cases. However, these differences did not have statistical significance. In addition, for the 'I do not know' responses, the mean scores of the proposed educational system in the two test cases (Tables 7-4 and 7-8 in Chapter 7) were smaller than for the real laboratory or no practical experience in the two test cases, but these differences also did not reach statistical significance, as indicated in Tables 7-5 and 7-9 in Chapter 7.

The results support the second hypothesis that students who used the proposed educational system with the Leap Motion controller understood the microscopic-level knowledge of the lessons better than those who used the real laboratory or only had the theoretical lesson without an active learning phase. In addition, the results indicate that students who used the proposed educational system with the mouse understood the microscopic-level knowledge of the lessons better than those who only had the theoretical lesson without an active learning phase.

Indeed, statistical differences were observed between students who used the proposed system and those who did not, supporting the hypothesis that using the proposed system may effectively help understand chemistry experiments at the microscopic level. In contrast, no significant differences were found in the mean learning achievement at the microscopic level between classes with students who used the real laboratory and classes who had the theoretical lesson alone, as listed in Tables 7-3 and 7-7 in Chapter 7. Thus, students who used the real laboratory obtained the same understanding of microscopic-level processes as students who did not physically perform the chemistry experiment. These results support the primary purpose of the proposed educational system, which is to combine practical knowledge with molecular representation to understand chemical theories and models and to assist users in understanding molecular structures and chemical bonds.

Additionally, various benefits of these results can be deduced. First, the results further confirm that active learning in many different forms has a clear advantage over passive learning. Moreover, concerning the peculiarity of the system, the interchangeability between a real laboratory and the developed educational system has clear advantages in practical terms; for example, students can complete experiments anytime and anywhere. According to the teachers' interviews, this functionality would solve the problem of how students complete experiments when they miss a class or the problem of increasing class sizes.

The proposed system can be used as exam practice to help students prepare for exams by reviewing their information and recognising their weaknesses. According to the interviewed teachers, these benefits are not available in a real laboratory. A further benefit of the proposed system can be observed when a real laboratory is not available, such as in the case of the coronavirus disease 2019 (COVID-19) pandemic, or when the necessary materials are missing or possibly hazardous. Finally, the proposed educational system could help distance-learning delivery in e-learning courses or massive open online courses, where the theory can be effectively complemented by practical experience in a virtual context.

In general, the study results reveal that, through combining chemistry simulation with molecular visualisation concepts, students can understand the objective of the chemistry experiments when using the proposed system as well as they do in a real laboratory. The findings demonstrate that students understand the microscopic explanations and concepts of the chemistry experiments using the Leap Motion controller better than in the real laboratory. Student understanding of the content and concepts is improved through this new method of interaction. Thus, using the Leap Motion technology has significant benefits for students in education.

Moreover, the educational system provides a unique learning method through virtual environments. Through the use of virtual representations and physico-chemical terms with gesture-based technology, students better comprehend complex molecular structures and the effect of macromolecular interactions on chemical bonds. Thus, the educational system increases the opportunity for students to apply and understand experiments and solves many issues that teachers face every day in teaching chemistry, supporting the research hypothesis and confirming its aim.

8.4 Chapter Summary

In this chapter, the research findings and the extent to which the research hypothesis is supported were studied by deriving and discussing the findings of developing the educational system and studying its effects on student learning and knowledge acquisition. Considering these together, the findings of developing the educational system indicate that the proposed system increases student learning achievements. The Leap Motion controller, 3D virtual environment, and molecular visualisation help students visualise and understand theoretical concepts and chemical reactions. The study results reveal the advantages of the proposed system and its ability to improve student understanding and knowledge of chemistry at the microscopic level. In addition, the results demonstrate the eligibility of the system to replace traditional teaching methods and overcome obstacles faced in teaching chemistry. The system was simple to use, and most users liked its user interface and showed interest in using the system again.

Chapter 9. CONCLUSION

9.1 Introduction

The previous chapters discuss the literature review and research objectives used to develop the concepts and methods of the study and design the proposed educational system. Numerous data were collected and analysed through several studies, following the research aim and set methodologies. As described, a chemistry educational system was developed based on using the Leap Motion controller, combining the macroscopic and microscopic views. This system was studied and evaluated concerning its usability and effectiveness in learning chemistry through three approaches: an interview study, usability testing and experimental study.

In light of the research findings and discussion, it is essential to summarise this research to demonstrate the effects of using gesture-based technology – the Leap Motion controller – and integrating simulation and molecular visualisation technologies in education to improve knowledge acquisition. Therefore, this chapter revisits the research aim and hypothesis and discusses and evaluates the findings of the research and presented studies. It also explores the influence and contributions of the research to the field of knowledge and the potential constraints and future studies.

9.2 Summary of Findings

This research aimed to identify the effects of using gesture-based technology and combining simulation and molecular visualisation in teaching chemistry. Therefore, in this research, an educational system combining simulations of chemistry experiments and the visualisation of molecules was designed for secondary school students based on a gesture-based device, the Leap Motion controller. The study aimed to identify the improvements in the teaching method and changes in the students' skills, knowledge acquisition and learning achievement due to their interaction with the new system. The principal research hypothesis was that using gesture-based technology and combining simulation and molecular visualisation technologies in education would positively influence knowledge acquisition and learning achievement.

This research examined the challenges of teaching chemistry and studied the use of different technologies and methodologies in education. The in-depth review, in Chapter 2, also critically analysed previous studies on virtual laboratories and molecular visualisation and studied their features and effects on education.

The concepts of HCI and gesture-based technology and their role in chemistry education were investigated. The study explored various methods for gesture-based interaction and their applications. The benefits of gesture-based interactions and the Leap Motion controller in chemistry education were investigated in Chapter 3.

This research presented the applied research methodologies in studying the system and its effects on the learning and teaching processes, including an interview study, usability testing and experimental study, as explained in Chapter 4.

The development of the educational system, including the system analysis, design and implementation, was detailed in Chapter 5. Before developing the chemistry educational system, the requirements were identified and presented based on the teachers' interview study. Further, the concepts regarding developing this chemistry educational system were illustrated in Chapter 5. The Leap Motion controller was integrated into the system due to its advanced capabilities and various features. By simulating a real laboratory, representing it in a 3D virtual environment and using gesture-based technology, the proposed educational system allows users to perform chemistry experiment procedures similar to a real laboratory.

CONCLUSION

This research presented a comprehensive system evaluation through interview study and usability testing. The results of both methods were detailed in Chapter 6. The results support the research hypothesis, demonstrating a compelling need, according to the interviewed chemistry teachers, for an educational system that simulates experiments when students cannot perform these experiments in a real laboratory for various reasons. The teachers believe that this system can help them teach complex concepts by combining simulation and molecular virtualisation using a 3D interface. In addition, the gesture-based device and real laboratory simulations assist in acquiring and understanding the knowledge and concepts of chemistry experiments. Furthermore, the results confirm that chemistry teachers find the system easy to use for students, as the Leap Motion controller provides natural interactions that more closely resemble real-world activities than the mouse.

Moreover, the system usability testing results reveal that users found the system easy to use. The results confirm that the system helped users comprehend the concepts behind the experiment tasks and scenarios. Moreover, users liked the overall system interface. In general, the Leap Motion controller was easier to use and more appealing than the mouse.

This research investigated the effects of the proposed educational system in a secondary school through an experimental study. This thorough investigation in Chapter 7 presents evidence to support the research hypothesis. The results indicate that the proposed system enables more effective learning than traditional teaching methods that do not apply the lesson in a real laboratory. The students who applied the theory using the proposed system understood the lesson better than students who were taught only the theoretical lesson. In addition, the proposed educational system presents a more convenient alternative to traditional methods that significantly enhances learning chemistry concepts.

CONCLUSION

Finally, this research comprehensively discussed the results of the three research methods. The discussion in Chapter 8 demonstrates that, compared with traditional methods, the proposed educational system positively affects student understanding of microscopic-level chemistry concepts. Students who applied the lesson using the proposed system with the Leap Motion controller understood the microscopic-level knowledge of the chemistry lesson better than students who applied it in the real laboratory and who were taught only the theoretical lesson. Furthermore, students who applied the lesson using the proposed system with the mouse better understood the microscopic-level knowledge of the chemistry lesson than students who were taught only the theoretical lesson.

Based on these findings, the research indicates that integrating simulation and molecular visualisation techniques with a gesture-based device favours knowledge acquisition, improves learning achievement and supports the educational process in chemistry education. Therefore, the combined use of the proposed system and real-world laboratories is recommended whenever possible, as the real laboratory may favour the acquisition of practical skills. Moreover, the proposed system delivers improved comprehension of the microscopic view of chemistry concepts.

In addition, this work proves that in improving the learning of chemistry subjects, the proposed educational system is sufficient when using a real laboratory is not possible, such as in the case of distance learning, absences, chemical unavailability, or simply the risk of using chemicals. The practical implementations of the system also enable teachers to visualise concepts in chemistry that were previously challenging to explain in traditional educational systems. The results confirm that gesture-based technologies can further improve the learning experience of students and can be used by anyone with sufficient knowledge of handling these tools. This development in teaching methods could enable students to learn actively with increased learning achievement.

9.3 Contribution of this Research

This interdisciplinary research encompasses HCI, software engineering, education and gesture-based technology. It focuses on using recent technologies in education, an essential element in improving and developing the learning experience in schools, and related advanced features and applications of such technologies. The use of gesture-based technology in chemistry simulation and molecular visualisation for education has been the subject of limited prior research. This section reviews the contributions made by this study to the existing knowledge in the field.

This research introduces a chemistry educational system that includes chemistry experiments designed for secondary schools. This system uses gesture-based technology and combines simulation and molecular visualisation to enhance the learning experience. This system improves students' knowledge acquisition and understanding of chemistry concepts. The system also overcomes the limitations of traditional teaching methods and enhances practical teaching to replace traditional teaching. The new methodology of teaching introduced by this educational system significantly improves educational systems, contributes to their development and provides considerable benefits.

The research presented a new learning method that integrates several technical concepts to improve the acquisition of knowledge and contribute to the development of the educational process. This proposed method of learning chemistry combines two views and uses gesture-based technology with virtual simulations. This method significantly improves student comprehension and increases their opportunity to perform and understand chemistry experiments. In particular, it improves student understanding of molecular concepts and addresses the challenges associated with learning the scientific principles of chemistry. Furthermore, it makes simulations more realistic compared to existing methods.

Therefore, this study also contributes to e-learning and the current debate on the value of technology in education and its ability to advance the quality and environment of learning.

This research reveals the significant role of gesture-based technology in education, where it can help streamline the learning experience. The research results proved the effectiveness and novelty of using gesture-based technology in the educational system, where it significantly affects creating successful learning outcomes for students, enhancing the educational process in schools. A complex operation, such as the simulation of chemistry experiments, can be presented in an effective and accessible manner while being easy to use through gesture-based technology.

Moreover, this research contributes to and supports studies on the Leap Motion controller specifications and applications. The study confirms that the Leap Motion controller is a device with great potential and has many applications in different subject areas. It demonstrates that the Leap Motion controller is designed to accomplish tasks such as swiping, tapping and movements to grab, move and rotate objects virtually through hand gestures. This study demonstrates that these features are useful and can effectively be used and integrated into the design of educational systems. As demonstrated by the research, gesture-based interfaces are important, altering how users interact with computers in new intuitive ways.

9.4 Research Limitations

This research faced several limitations and difficulties. First, the lack of supportive resources in designing and programming a system using the Leap Motion controller was a critical limitation, as this research began in 2014 and the Leap Motion controller was only released in 2013. Furthermore, the absence of recent empirical findings on the topic of the Leap Motion controller to support the literature study and understanding of this new research topic and methods of investigation is a fundamental limitation. However, this research attempted to overcome these obstacles through continuous research, practice and participation in international conferences.

Second, severe constraints were encountered in selecting and preparing the sample and collecting adequate data. It was difficult to obtain school approval, and several schools refused to participate. Then, finding an appropriate number of classrooms and students to test the system and determine the appropriate time to begin the study were obstacles that needed to be overcome in this research.

Third, the measures used to collect the data had limitations in this study. Test questions were developed for the two chemistry lessons to assess the effectiveness of the proposed system in learning achievement. In deciding who should write the test questions, two options were available. The first option was that a chemistry teacher should do so, offering greater reliability because this is the standard method used by schools. Teachers are more experienced in this field, but a potential disadvantage is that the questions may not comply with the researcher's requirements. The second option was that the researcher should write the questions, with the advantage of ensuring that the measured influences are covered in the questions. However, this option carries the possible disadvantage that the researcher may lack experience teaching chemistry and designing questions, leading to unrealistic or unreliable results. As a result, the first option was selected to give the results more credibility, even if this led to deficiencies in some study aspects.

Fourth, time was a significant factor in this research. The development of software and technology in the research field is a fast-growing field, and it is challenging to keep abreast of the rapid developments in these technologies. Conversely, experimental and field studies take a long time for assessment, planning, preparation and execution. Balancing these two aspects was one of the most significant challenges encountered in this research.

9.5 Suggestions for Future Research

This research provided a starting point for understanding the effects of gesture-based technology in secondary school education. The research findings and limitations may lead to subsequent critical studies for various academic purposes. The following are areas for consideration.

The proposed system could be studied with more chemistry lessons and more complex topics to further illustrate the effect of integrating macroscopic and microscopic representations in student understanding of the lessons. Additionally, the proposed system should include additional chemistry lessons geared towards assisting teachers in harnessing its benefits.

The proposed system requires additional examination by teachers with diverse experiences and educational backgrounds to weigh its benefits, drawbacks and gather the most reliable and diverse results by applying the experimental study in different schools and countries. Continuing this research and introducing it to different educational organisations has apparent implications.

Moreover, improving and developing the gesture-based interaction in the proposed system using a VR headset compatible with the Leap Motion controller, such as Oculus Rift (Oculus, 2020) or HTC Vive (HTC, 2021), could be explored.

CONCLUSION

In the future, the author's main aim is to continue to contribute to the existing knowledge and publications on using gesture-based technology in developing software. Moreover, the author aims to communicate with other researchers to study the effects of this technology on different applications.

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Appendices

Appendix A – User Requirements Interview Questions

<u>Participant Information Sheet</u>

<u>Dear teacher:</u>

I am currently a PhD student at Plymouth University, UK. My research is about using the Leap Motion controller in educational systems. The research aims to study the impact of using gesture-based technology, the Leap Motion controller, in education and discovering the effect of the integration of simulation and molecular visualisation as a teaching method. This research presents a chemistry learning system designed for secondary school students.

This interview aims to gain your perspective and define your requirements as a teacher and the students' requirements as users of the educational system. This interview purpose is to identify the difficulties that teachers face permanently. Problems related to teaching the macroscopic and microscopic level to chemistry experiments will be discussed. Also, the potential solutions will be identified. User requirements related to the macroscopic and microscopic level for chemistry experiments, general user requirements, and system specifications will be defined.

Participation in this study provides all participants with the opportunity to contribute to new research. The presented technology in this research aims to increase the education flexibility and accessibility. This research seeks through the presented system to develop and enhance many learning skills, in addition to many teaching strategies, such as cooperative and active learning. It also aims to increase students' motivation for learning and interaction between students and teachers.

The interview will take about an hour in Arabic, and your answers will be written during the interview. Interviews are analysed by applying qualitative analysis to all questions.

Participation in this study is voluntary and you can withdraw from it any time without penalty. Also, there are no risks or difficulties in taking part in this study. If you feel uncomfortable at any time, you can take a rest, reschedule the meeting, or withdraw from this study.

All the information and the interview will be processed confidentially. The data source will not be published or identified. Your identity will be anonymous and no personal information will be used. In addition, all data will be stored securely for a period of ten years from the date of the study. Then it will be safely destroyed when not needed.

If you have any question or any further quires, please do not hesitate to contact by the below emails.

shaykhah.aldosari@plymouth.ac.uk, davide.marocco@plymouth.ac.uk

I thank and appreciate your fruitful efforts

The researcher: Shaykhah Aldosari

Consent to participate in the interview study

1. I confirm that I have read and discussed with the researcher the above Participant Information Sheet for the study. I understand the aims of this research, the interview process, the data that will be recorded, and how it will be recorded.
2. I confirm that I have studied and understood the information detailed in the Participant Information Sheet, have asked questions and received satisfactory answers.
3. I understand that every effort will be made to maintain the confidentiality of my information and the identification details will be changed in the research, to protect identities as much as possible.
4. I understand that all data will be kept securely for a period of 10 years once the study is completed and destroyed once that period has elapsed.
5. I understand that my participation in the study is completely voluntary and I can withdraw without giving a reason and without negative consequences. Also, my right to withdraw my data, even when I conceal my identity, has been fully explained to me.
6. A clear explanation of the complaints procedures was provided, and I have contact details for the researcher and the study supervisor.
7. All potential benefits, risks, or inconveniences were explained to me and I was given a written copy of this to keep for future reference, including the contact details that enable me to get support when needed.

Teacher number:

Teacher name:

School:

Date:

Signature:

Interview Questions

1. Could you please introduce yourself?

2. I would like to know the most important problems you face in teaching chemistry. Could you please explain them in details?

3. In your opinion, what is the main cause of these problems?

4. Have you tried to solve these problems before? And how?

5. Have you tried using an educational system that represents chemical compounds in 3D?

6. What do you think we can offer more than the representations of chemical compounds?

7. What do you think if chemical compounds can be displayed before they interact and then during the reaction? Therefore, the user can see how the chemical bonds break down and then reform to build new compounds after the reaction.

8. What do you think you need in an educational system?

9. After the compounds form, would it be useful if the student could browse the new molecules and examine them from all sides?

10. What about the laboratory and performing experiments? Do you have any difficulties with them?

11. Are all of the students doing most experiments individually?

12. If no, what do you do in such situations?

13. Do you think you need a system that simulates the chemistry experiments of secondary school grads?

14. Why? Please explain?

15. The proposed system will be different from what you have already experienced. The simulator system will allow the user to interact with the system and perform each procedure in a similar manner to what she does in the real laboratory.

16. What are the features you want in such a system that simulates performing experiments in the real laboratory?

17. What about the steps of the experiments, what is the most important thing you want from this point of view?

18. Is it important in your opinion to put notes and instructions for the student at each step to help her perform them?

19. Does the school have student computers?

20. Do students have enough experience to use?

21. I will design an educational system that integrates the idea of laboratory simulation with molecular representation. So, the student will be able to do the chemistry experiment step by step as in the real laboratory. Then, he/ she will move into the micro-level and see the molecular structures of the chemical compounds and how the compounds were before the reaction.

Then, the user can interact with the chemical compounds directly and observe how the movement of molecules, the breaking of the bonds and the construction of the new bonds.

In addition, the user can identify how the final chemical compounds are formed and what are their components including atoms, bonds, and electrons. Finally, he/she can browse these final compounds in all dimensions. What do you think about it?

22. The system will be designed to allow the student to interact directly with the system and it will use the Leap Motion controller as an input device to increase this interaction. Have you ever try it?

23. I will show you a video to give you a simple idea of its features and how to use it.

24. Do you have any further questions you would like to ask me or any suggestion?

25. Can I contact you again if I need to ask more questions or test the system after implemented it?

Appendix B – User Requirements Interview Transcript

Interviewer: I am, Shaykhah Aldosari, a PhD student at Plymouth University. I am designing an educational system for secondary school chemistry students. Could you please introduce yourself before we start?

Interviewee 1: I am a teacher and I have been working as a chemistry teacher for secondary school for 12 years in public schools for girls.

I have already taught in several schools. I have a Bachelor degree in Education chemistry and I am studying for a Master of Education in Curriculum and Methods of Teaching.

Interviewee 2: I am a teacher and I have been working as a teacher for six years in secondary schools for girls. I have already studied chemistry for all secondary grades.

Interviewer: First, I would like to know the most important problems you face in teaching chemistry.

Interviewee 1: One of the most important problems we face is the students' understanding of chemical equations and reactions.

Interviewee 2: Yes, that is right. Students' understanding of chemical equations and the molecular structure of compounds is one of the main problems.

Interviewer: How so? Could you please explain more?

Interviewee 2: Some students cannot imagine the molecular structure and chemical bonds.

Interviewee 1: They cannot understand how chemical compounds interact and the breakdown of chemical bonds and how new chemical compounds were formed.

Interviewer: In your opinion, what is the main cause of this problem?

Interviewee 1: The reason, in my view, is the difficulty of imagining the molecular structure for students when they see chemical symbols and formulas only.

Interviewee 2: Yes, in my opinion, this is the reason.

Interviewer: Have you tried to solve this problem before? And how?

Interviewee 2: We use ready-made images of molecular structures of some compounds and display them using a projector.

Interviewee 2: And we also use the drawing on the blackboard to explain the steps, but, in my opinion, students cannot imagine the whole process through the drawing on the blackboard only.

Interviewee 1: Yes. In addition, I cannot draw all of these molecules for them, and these drawings give only a general view without details of the interaction process.

In intermediate school grads, teachers use some models to illustrate chemical compounds and concepts. However, we cannot do that in secondary school grads.

Interviewer: Why?

Interviewee 1: Because chemical compounds are more complex and numerous, it also takes time and is also costly.

Interviewer: Can we say that you need to represent these chemical compounds in 3D?

Interviewee 1: Yes.

Interviewee 2: Yes, that will change very much in our teaching method.

Interviewer: Have you tried using an educational system that represents chemical compounds in 3D?

Interviewee 1: No, I have not.

Interviewee 2: Yes. I used a one before. In this system, I enter the chemical formula. Then, the image of the molecular structure of the compound appears.

Interviewer: That's good, but what do you think we can offer more than the representations of chemical compounds?

Interviewee 2: You can see representations of the molecular structure of the compounds before and after the reaction.

Interviewee 1: Yes. That is very important.

Interviewer: What do you think if chemical compounds can be displayed before they interact and then during the reaction? Therefore, the user can see how the chemical bonds break down and then reform to build new compounds after the reaction.

Interviewee 2: This will be excellent and will make it much easier for us.

Interviewee 1: Yes. Presenting the molecules before the reaction, during the reaction, and then after the interaction will explain to the student how chemical bonds break up and rebuild new chemical bonds.

Interviewee 2: Is it possible to design all this in a three-dimension?

Interviewer: Yes, I will do it.

Interviewee 1: Yes, but the molecules should display in the ball and stick molecular model and the colours must match the standard colours.

Interviewee 2: Yes, the results should be correct and don't contain errors as this may distract the students.

Interviewer: I will take care of that.

After the compounds form, would it be useful if the student could browse the new molecules and examine them from all sides?

Interviewee 1: Yes. It is good and will increase the student's understanding.

Interviewee 2: Yes. Especially for the complex long molecules, but it should be easy to use. So, all of the students can use it effectively.

Interviewee 1: Yes and it should not take a long time in this process because time is an important factor in the educational process.

Interviewer: What about the laboratory and performing experiments? Do you have any difficulties with them?

Interviewee 1: Yes, we face some difficulties such as lack of chemicals and lack of time to complete long experiments, but we are trying to overcome these problems by working hard.

Interviewer: What about you teacher?

Interviewee 2: Yes, we face these problems. We cannot perform some experiments for the reasons stated by my colleague. Also, we cannot re-do the experiments for absent students because of a lack of time.

Interviewer: Are all of the students doing most experiments individually?

Interviewee 1: No.

Interviewee 2: No, they aren't. In some experiments, chemicals are dangerous, unavailable, or available but not enough for all of the students.

Interviewer: What do you do in such situations?

Interviewee 1: If the chemicals are available but in a small amount, I just do the experiment and ask them to observe the results. Sometimes if the amount of chemicals is sufficient, we put the students in groups to do the experiment.

Interviewee 2: If the chemicals are very dangerous, performing the experiment is unauthorized for the students' safety. So, I just show a video of the experiment if I can find it online.

Interviewer: Do you think you need a system that simulates the chemistry experiments of secondary school grads?

Interviewee 1: Yes. We really need it, especially for long and dangerous experiments and for experiments in which their chemicals are often not available.

Interviewee 2: Yes but I tried some programs that were not good.

Interviewer: Why? Please explain?

Interviewee 2: It was just a few buttons we pressed to display animation for each step of the experiment and this is not much different from the video.

Interviewer: The system will be different from what you have already experienced. The simulator system will allow the user to interact with the system and perform each procedure in a similar manner to what she does in the real laboratory.

Interviewee 1: This would be very helpful.

Interviewee 2: This is a good idea.

Interviewer: What are the features you want in such a system that simulates performing experiments in the real laboratory?

Interviewee 1: Laboratory glassware, equipment such as Bunsen Burners, should be designed similar to the real ones.

Interviewee 2: Yes and also the nature of chemicals including colour, hardness, and shape should be close to reality.

Interviewer: What about the steps of the experiments, what is the most important thing you want from this point of view?

Interviewee 2: The student should be able to perform the experiments step by step without integrating the steps and the system should illustrate the results of each step.

Interviewee 1: Also, the results should be accurate and correct as described in the books.

Interviewer: Is it important in your opinion to put notes and instructions for the student at each step to help her perform them?

Interviewee 1: That is really important and good.

Interviewee 2: Yes, and we will not need to submit paper notes to the students, and they may be able to do experiments by themselves without much help from me as a teacher.

Interviewer: Does the school have student computers?

Interviewee 1: Yes. All the schools have a computer lab that has enough computers that students can use.

Interviewer: Do students have enough experience to use?

Interviewee 1: Yes, the computer science and information course is a major course in all schools.

Interviewer: I will design an educational system that integrates the idea of laboratory simulation with molecular representation. So, the student will be able to do the chemistry experiment step by step as in the real laboratory. Then, he/ she will move into the micro-level and see the molecular structures of the chemical compounds and how the compounds were before the reaction.

Then, the user can interact with the chemical compounds directly and observe how the movement of molecules, the breaking of the bonds and the construction of the new bonds.

In addition, the user can identify how the final chemical compounds are formed and what are their components including atoms, bonds, and electrons. Finally, he/she can browse these final compounds in all dimensions.

What do you think?

Interviewee 1: That would be really wonderful.

Interviewee 2: Yes, it is an excellent idea, and will you provide many experiments in this system?

Interviewer: We will initially provide a limited number of experiments to test their effectiveness.

Interviewee 1: How will you be able to provide this interaction?

Interviewer: The system will be designed to allow the student to interact directly with the system and it will use the Leap Motion controller as an input device to increase this interaction.

Have you ever try it?

Interviewee 1: I haven't heard about it.

Interviewee 2: No.

Interviewer: I will show you a video to give you a simple idea of its features and how to use it.

After watching the video the two teachers tried the Leap Motion controller.

Interviewee 2: Is it expensive?

Interviewer: No, it is not too expensive. Its price is 280SR

Interviewee 2: What if we cannot provide it to the students?

Interviewer: If it is not available, the system will allow the user to the mouse instead.

Interviewee 1: That's excellent. I'm excited to use the system.

Interviewee 2: Yes, I hope to try it soon and thank you for your consideration.

Interviewer: Do you have any further questions you would like to ask me or any suggestion?

Interviewee 1: No.

Interviewee 2: No. thanks.

Interviewer: Can I contact you again if I need to ask more questions or test the system after implemented it?

Interviewee 1: Yes, of course.

Interviewee 2: Yes, you can.

Interviewer: Thank you for your time and cooperation. My best regards to you.

Interviewee 1: You are welcome.

Interviewee 2: Welcome.

Appendix C – Teachers' Interview Questions

<u>Participant Information Sheet</u>

Dear teacher:

I am currently a PhD student at Plymouth University, UK. My research is about using the Leap Motion controller in educational systems. The research aims to study the impact of using gesture-based technology, the Leap Motion controller, in education and discovering the effect of the integration of simulation and molecular visualisation as a teaching method. This research presents a chemistry learning system designed for secondary school students.

The aim of this interview study is to test the system to ensure quality results in the educational environment. This interview purpose to evaluate the results of this system, and identify your viewpoint, your positive and negative feedback after trying the system. Additionally, your previous experiences in using other educational systems and the problems you face will be discussed. Your opinion on the presented system such as its features, usability, and the ability to gain knowledge from the system will also be discussed.

Participation in this study provides all participants with the opportunity to contribute to new research. The presented technology in this research aims to increase the education flexibility and accessibility. This research seeks through the presented system to develop and enhance many learning skills, in addition to many teaching strategies, such as cooperative and active learning. It also aims to increase students' motivation for learning and interaction between students and teachers.

The interview will take about 45-60 minutes in Arabic, and your answers will be written during the interview. Interviews are analysed by applying qualitative analysis to all questions.

Participation in this study is voluntary and you can withdraw from it any time without penalty. Also, there are no risks or difficulties in taking part in this study. If you feel uncomfortable at any time, you can take a rest, reschedule the meeting, or withdraw from this study.

All the information and the interview will be processed confidentially. The data source will not be published or identified. Your identity will be anonymous and no personal information will be used. In addition, all data will be stored securely for a period of ten years from the date of the study. Then it will be safely destroyed when not needed.

If you have any question or any further quires, please do not hesitate to contact by the below emails.

shaykhah.aldosari@plymouth.ac.uk, davide.marocco@plymouth.ac.uk

I thank and appreciate your fruitful efforts

The researcher: Shaykhah Aldosari

Consent to participate in the interview study

1. I confirm that I have read and discussed with the researcher the above Participant Information Sheet for the study. I understand the aims of this research, the interview process, the data that will be recorded, and how it will be recorded.
2. I confirm that I have studied and understood the information detailed in the Participant Information Sheet, have asked questions and received satisfactory answers.
3. I understand that every effort will be made to maintain the confidentiality of my information and the identification details will be changed in the research, to protect identities as much as possible.
4. I understand that all data will be kept securely for a period of 10 years once the study is completed and destroyed once that period has elapsed.
5. I understand that my participation in the study is completely voluntary and I can withdraw without giving a reason and without negative consequences. Also, my right to withdraw my data, even when I conceal my identity, has been fully explained to me.
6. A clear explanation of the complaints procedures was provided, and I have contact details for the researcher and the study supervisor.
7. All potential benefits, risks, or inconveniences were explained to me and I was given a written copy of this to keep for future reference, including the contact details that enable me to get support when needed.

Teacher number:

Teacher name:

School:

Date:

Signature:

Interview Questions

1. What is your current position and title?
2. How long have you held this position?
3. Where do you currently work?
4. What is your current level of education?
5. Do you use a computer?
6. How often do you use the computer?
7. How would you rate your computer skills?
8. Have you used any e-learning system before in your class? If yes, describe these systems.
9. Have you used any simulation learning system before in your class? If yes, describe these systems.
10. What is your overall impression of the system?
11. Do you feel this system is current? Why?
12. How easy is it to use the system?
13. How easy is it to complete the tasks?
14. What do you think about the input devices?
15. Do you like the interface of the system?
16. Does the system provide information that meets your needs?
17. Do you think the students will be able to use the system and complete the tasks without help?
18. Do you think the system can help students to understand the concepts of the experiments? Why?

19. On a scale of 1 to 5 (where 1 stands for not at all and 5 very much), how much do you think the system can help students to understand the concepts of the experiments?

20. What did you like best about the system?

21. What did you like least about the system?

22. If you were the system developer, what would be the first thing you would do to improve the system?

23. Is there anything that you feel is missing from this system? (Probe: content or features/functions)

24. Would you like to use this system for your class?

25. Do you have any other final comments or questions?

Appendix D – Teachers' Interview Transcript

Interview 1:

Interviewer: What is your current position and title?

Interviewee 1: I work as a teacher.

Interviewer: How long have you held this position?

Interviewee 1: For five years.

Interviewer: Where do you currently work?

Interviewee 1: I work in a secondary school for girls.

Interviewer: What is your current level of education?

Interviewee 1: I have a bachelor's degree.

Interviewer: Do you use a computer?

Interviewee 1: Yes, I use the computer.

Interviewer: How often do you use the computer?

Interviewee 1: I use the computer often.

Interviewer: How would you rate your computer skills?

Interviewee 1: My skills in using the computer is rated as excellent.

Interviewer: Have you used any e-learning system before in your class? If yes, describe these systems.

Interviewee 1: Yes, I have used more than one program and they were good, but not enough, some of them are intended for building molecules only and some of them are intended for the visualisation of molecules only.

Interviewer: Have you used any simulation learning system before in your class? If yes, describe these systems.

Interviewee 1: I haven't used any simulation learning system before in my class.

Interviewer: What is your overall impression of the system?

Interviewee 1: The program is unique and multi-tasking. It includes performing chemistry experiments and designing chemical molecules

Interviewer: Do you feel this system is current? Why?

Interviewee 1: Yes, honestly, it is unique and modern and it keeps pace with advances in technology.

Interviewer: How easy is it to use the system?

Interviewee 1: It is easy to use.

Interviewer: How easy is it to complete the tasks?

Interviewee 1: I completed all the tasks easily without any problems.

Interviewer: What do you think about the input devices?

Interviewee 1: Leap motion: it is unique and provides more interaction. Mouse: it is also an excellent device.

Interviewer: Do you like the interface of the system?

Interviewee 1: Yes, I like it. The graphics are fantastic and the molecular visualisation is a three-dimensional representation. You can rotate the chemical molecules to explore them.

Interviewer: Does the system provide information that meets your needs?

Interviewee 1: Yes and it can often obviate the need for a theoretical explanation.

Interviewer: Do you think the students will be able to use the system and complete the tasks without help?

Interviewee 1: Yes, they will. The program is easy to use and also the students are smart.

Interviewer: Do you think the system can help students to understand the concepts of the experiments? Why?

Interviewee 1: Yes, it will help students to understand the concepts of the experiments. It obviates the need for a theoretical explanation and applying the experiments in labs. Especially, we cannot apply all the lab experiments. In some experiments, I am the only one who can do it, and students can just watch me. However, this application can help everyone to do the experiments.

Interviewer: On a scale of 1 to 5 (where 1 stands for not at all and 5 very much), how much do you think the system can help students to understand the concepts of the experiments?

Interviewee 1: I give it 5.

Interviewer: What did you like best about the system?

Interviewee 1: I liked the accuracy of experimental steps and three-dimensional representation of molecules. I also liked that you can rotate the chemical molecules to explore them.

Interviewer: What did you like least about the system?

Interviewee 1: When you use the mouse, the interaction becomes less.

Interviewer: If you were the system developer, what would be the first thing you would do to improve the system?

Interviewee 1: I will add sounds effects.

Interviewer: Is there anything that you feel is missing from this system? (Probe: content or features/functions)

Interviewee 1: No, there is not.

Interviewer: Would you like to use this system for your class?

Interviewee 1: Yes, of course, I would like to use it.

Interviewer: Do you have any other final comments or questions?

Interviewee 1: Thank you for your consideration of developing educational applications because we strongly need them.

Interview 2:

Interviewer: What is your current position and title?

Interviewee 2: I work as a teacher.

Interviewer: How long have you held this position?

Interviewee 2: For six years.

Interviewer: Where do you currently work?

Interviewee 2: I work in a secondary school for girls.

Interviewer: What is your current level of education?

Interviewee 2: I have a bachelor's degree.

Interviewer: Do you use a computer?

Interviewee 2: Yes, I use the computer.

Interviewer: How often do you use the computer?

Interviewee 2: I always use the computer.

Interviewer: How would you rate your computer skills?

Interviewee 2: My skills are excellent at using the computer.

Interviewer: Have you used any e-learning system before in your class? If yes, describe these systems.

Interviewee 2: Yes, I have used different programs. They display molecule visualisations of chemical compounds or play videos of the steps of the experiments.

Interviewer: Have you used any simulation learning system before in your class? If yes, describe these systems.

Interviewee 2: Yes, I have used one program. It was displaying a list of experiment steps. When you press on any step, it shows a flash video and automatically executes this step.

Interviewer: What is your overall impression of the system?

Interviewee 2: Honestly the system is greatly wonderful. I expect students will like it and it will get their attention.

Interviewer: Do you feel this system is current? Why?

Interviewee 2: Yes, I feel that it is current because I haven't seen anything like this before and it uses a new input device.

Interviewer: How easy is it to use the system?

Interviewee 2: It is easy to use.

Interviewer: How easy is it to complete the tasks?

Interviewee 2: Completing the tasks was very easy.

Interviewer: What do you think about the input devices?

Interviewee 2: Leap motion: it is better because the student can practise as if she is in a real lab. Mouse: it is a good device.

Interviewer: Do you like the interface of the system?

Interviewee 2: The interface of the system is wonderful and the colours of chemical compounds and materials are close to reality.

Interviewer: Does the system provide information that meets your needs?

Interviewee 2: Yes, it does and it will solve many of the problems that we always face, such as lack of materials, increasing class sizes, re-applying the experiments and preparing for exams.

Interviewer: Do you think the students will be able to use the system and complete the tasks without help?

Interviewee 2: There is no doubt in this. Nowadays, Students know how to deal with technology and they love it. Generally, it is an easy-to-use program.

Interviewer: Do you think the system can help students to understand the concepts of the experiments? Why?

Interviewee 2: Yes, it will help students to understand the concepts of the experiments. Because after doing the experiment, the user can explore and recognise the chemical compounds and understand what happened to the bonds between atoms.

Interviewer: On a scale of 1 to 5 (where 1 stands for not at all and 5 very much), how much do you think the system can help students to understand the concepts of the experiments?

Interviewee 2: I give it 5.

Interviewer: What did you like best about the system?

Interviewee 2: I liked moving from macro-level to micro-level. I also liked how the chemical bonds are broken at the micro-level and combined again after the chemical interaction.

Interviewer: What did you like least about the system?

Interviewee 2: I don't like that the instructions are in English.

Interviewer: If you were the system developer, what would be the first thing you would do to improve the system?

Interviewee 2: I feel it can include more experiments and more complicated subjects.

Interviewer: Is there anything that you feel is missing from this system? (Probe: content or features/functions)

Interviewee 2: The system is great. I don't think anything is missing.

Interviewer: Would you like to use this system for your class?

Interviewee 2: Yes, I would like to use it.

Interviewer: Do you have any other final comments or questions?

Interviewee 2: Thank you for the system and I hope we get a copy of it.

Interview 3:

Interviewer: What is your current position and title?

Interviewee 3: I work as a teacher.

Interviewer: How long have you held this position?

Interviewee 3: For 12 years.

Interviewer: Where do you currently work?

Interviewee 3: I work in a secondary school for girls.

Interviewer: What is your current level of education?

Interviewee 3: I have a bachelor's degree.

Interviewer: Do you use a computer?

Interviewee 3: Yes, I use the computer.

Interviewer: How often do you use the computer?

Interviewee 3: I always use the computer.

Interviewer: How would you rate your computer skills?

Interviewee 3: My skills are good.

Interviewer: Have you used any e-learning system before in your class? If yes, describe these systems.

Interviewee 3: Yes, I have used Edmodo. It is a website that offers many tools to help you communicate with the students, submit assignments, create quizzes and grade them.

Interviewer: Have you used any simulation learning system before in your class? If yes, describe these systems.

Interviewee 3: Yes, I used a flash video to explain the chemistry experiments by selecting the name of a specific experiment, and then this experiment is executed automatically.

Interviewer: What is your overall impression of the system?

Interviewee 3: It is excellent. It makes explaining the experiments in the classroom is more easily and increases student understanding.

Interviewer: Do you feel this system is current? Why?

Interviewee 3: Yes, because it does not do the experiments automatically, but it asks you to add materials and stirs them. It also allows you to watch the components of molecules, and this is difficult to do in the real lab.

Interviewer: How easy is it to use the system?

Interviewee 3: It is easy to use, but you need to practise to be professional.

Interviewer: How easy is it to complete the tasks?

Interviewee 3: All the tasks were easy and clear.

Interviewer: What do you think about the input devices?

Interviewee 3: The mouse is a good and available device, but the leap motion controller is better and provides more simulated reality.

Interviewer: Do you like the interface of the system?

Interviewee 3: Yes, I like it. Especially, molecules represented in 3d structures.

Interviewer: Does the system provide information that meets your needs?

Interviewee 3: Yes. I can use the system only without doing the experiments in the real laboratory. Especially, if tools or materials are unavailable or some of the material may cause danger to students.

Interviewer: Do you think the students will be able to use the system and complete the tasks without help?

Interviewee 3: Yes. The system is easy to use. Now, students prefer educational technology.

Interviewer: Do you think the system can help students to understand the concepts of the experiments? Why?

Interviewee 3: Yes, because by interacting with molecules they can identify how atoms and molecules interacted and how they were formed

Interviewer: On a scale of 1 to 5 (where 1 stands for not at all and 5 very much), how much do you think the system can help students to understand the concepts of the experiments?

Interviewee 3: I give it 5.

Interviewer: What did you like best about the system?

Interviewee 3: The leap motion controller, the realistic simulation, and steps of experiments are writing.

Interviewer: What did you like least about the system?

Interviewee 3: There are only a few experiments.

Interviewer: If you were the system developer, what would be the first thing you would do to improve the system?

Interviewee 3: I will add more experiments to cover all the experiments in the student book.

Interviewer: Is there anything that you feel is missing from this system? (Probe: content or features/functions)

Interviewee 3: No.

Interviewer: Would you like to use this system for your class?

Interviewee 3: Yes, it will help me to explain experiments in my class.

Interviewer: Do you have any other final comments or questions?

Interviewee 3: Thank you very much for this distinctive application.

Interview 4:

Interviewer: What is your current position and title?

Interviewee 4: I work as a teacher.

Interviewer: How long have you held this position?

Interviewee 4: For 18 years.

Interviewer: Where do you currently work?

Interviewee 4: I work in a secondary school for girls.

Interviewer: What is your current level of education?

Interviewee 4: I have a bachelor's degree.

Interviewer: Do you use a computer?

Interviewee 4: Yes, I use the computer.

Interviewer: How often do you use the computer?

Interviewee 4: I use the computer moderately.

Interviewer: How would you rate your computer skills?

Interviewee 4: My skills are moderate at using the computer.

Interviewer: Have you used any e-learning system before in your class? If yes, describe these systems.

Interviewee 4: Yes, I have used some e-learning systems, such as interactive whiteboard and programs for displaying molecular visualisation.

Interviewer: Have you used any simulation learning system before in your class? If yes, describe these systems.

Interviewee 4: No, I have not used any simulation learning system before in my class.

Interviewer: What is your overall impression of the system?

Interviewee 4: The system is excellent because it simulates reality and shows 3D molecular visualisation.

Interviewer: Do you feel this system is current? Why?

Interviewee 4: Yes. I haven't seen any application of simulation experiments before.

Interviewer: How easy is it to use the system?

Interviewee 4: It is easy to use. You don't need to practice long.

Interviewer: How easy is it to complete the tasks?

Interviewee 4: I apply all the experiments and complete all tasks easily.

Interviewer: What do you think about the input devices?

Interviewee 4: The Leap motion controller is an amazing new device. It makes the application more effective while the mouse is an easy-to-use and fast device.

Interviewer: Do you like the interface of the system?

Interviewee 4: Yes, the graphics are wonderful and better than the blackboard drawing.

Interviewer: Does the system provide information that meets your needs?

Interviewee 4: Yes, it does, but it does not obviate the need for a theoretical explanation

Interviewer: Do you think the students will be able to use the system and complete the tasks without help?

Interviewee 4: Yes, I think that but maybe some students need the user manual.

Interviewer: Do you think the system can help students to understand the concepts of the experiments? Why?

Interviewee 4: Yes, it will help students to understand the concepts of the experiments. They can re-apply the experiment more than once until they got it and the micro-level explains how it happened.

Interviewer: On a scale of 1 to 5 (where 1 stands for not at all and 5 very much), how much do you think the system can help students to understand the concepts of the experiments?

Interviewee 4: I give it 4.

Interviewer: What did you like best about the system?

Interviewee 4: I liked how it combines the macro-level with the micro-level.

Interviewer: What did you like least about the system?

Interviewee 4: I don't like that It is software so, it can be disrupted. Also, the steps instructions are in English.

Interviewer: If you were the system developer, what would be the first thing you would do to improve the system?

Interviewee 4: Ill change the instructions' language.

Interviewer: Is there anything that you feel is missing from this system? (Probe: content or features/functions)

Interviewee 4: Instructions can be in Arabic.

Interviewer: Would you like to use this system for your class?

Interviewee 4: Yes, I would like to use it in my class.

Interviewer: Do you have any other final comments or questions?

Interviewee 4: No. thanks.

Interview 5:

Interviewer: What is your current position and title?

Interviewee 5: I work as a teacher.

Interviewer: How long have you held this position?

Interviewee 5: For ten years.

Interviewer: Where do you currently work?

Interviewee 5: I work in a secondary school for girls.

Interviewer: What is your current level of education?

Interviewee 5: I have a bachelor's degree.

Interviewer: Do you use a computer?

Interviewee 5: Yes, I use the computer.

Interviewer: How often do you use the computer?

Interviewee 5: I use the computer moderately.

Interviewer: How would you rate your computer skills?

Interviewee 5: My skills are good.

Interviewer: Have you used any e-learning system before in your class? If yes, describe these systems.

Interviewee 5: Yes, I have used a program that includes the periodic table and the chemical equation calculator to calculate the chemical equations such as gas equations and spectroscopy equations.

Interviewer: Have you used any simulation learning system before in your class? If yes, describe these systems.

Interviewee 5: No, I have not used any simulation learning system before.

Interviewer: What is your overall impression of the system?

Interviewee 5: The system is excellent.

Interviewer: Do you feel this system is current? Why?

Interviewee 5: Yes, I feel that it is current because it uses new techniques through hand motion sensor and chemistry experiments simulation.

Interviewer: How easy is it to use the system?

Interviewee 5: As a first-time use, it is easy to use.

Interviewer: How easy is it to complete the tasks?

Interviewee 5: I complete all tasks easily. The system shows the instructions and steps for the user clearly.

Interviewer: What do you think about the input devices?

Interviewee 5: They are very good and I have liked the leap motion controller as a new device as it helps to simulate the movement of the hand.

Interviewer: Do you like the interface of the system?

Interviewee 5: Yes, I liked the system interface. It shows a virtual chemistry laboratory that is equipped with all the required materials and tools to do the experiment.

Interviewer: Does the system provide information that meets your needs?

Interviewee 5: Yes, it does and the information was provided in a clear and very understandable manner to complete the experiment tasks easily.

Interviewer: Do you think the students will be able to use the system and complete the tasks without help?

Interviewee 5: Yes. It is easy to use and instructions appear clearly written

Interviewer: Do you think the system can help students to understand the concepts of the experiments? Why?

Interviewee 5: Yes, it will help students to re-apply the experiment more than once and understand the molecules' interactions and forming bonds.

Interviewer: On a scale of 1 to 5 (where 1 stands for not at all and 5 very much), how much do you think the system can help students to understand the concepts of the experiments?

Interviewee 5: I give it 5.

Interviewer: What did you like best about the system?

Interviewee 5: I liked hand simulation, grabbing the glassware and the lab designing.

Interviewer: What did you like least about the system?

Interviewee 5: The lab background colour is dark. I prefer light colours.

Interviewer: If you were the system developer, what would be the first thing you would do to improve the system?

Interviewee 5: Change the background colour.

Interviewer: Is there anything that you feel is missing from this system? (Probe: content or features/functions)

Interviewee 5: Nothing is missing but I wish the system had included additional experiments.

Interviewer: Would you like to use this system for your class?

Interviewee 5: Yes, I would like to use it. It is a useful tool to help students to understand the concepts of the experiments

Interviewer: Do you have any other final comments or questions?

Interviewee 5: I hope that it will become available for teachers and students soon.

Appendix E – System Usability Test Survey in English

<u>Participant Information Sheet</u>

Dear Participant:

I am currently a PhD student at Plymouth University, UK. My research is about using the Leap Motion controller in educational systems. The research aims to study the impact of using gesture-based technology, the Leap Motion controller, in education and discovering the effect of the integration of simulation and molecular visualisation as a teaching method. This research presents a chemistry learning system designed for secondary school students.

The questionnaire aims to use and assess the system usability, then the results will analysed to evaluate and study the system interface and design and present the information and knowledge.

As a participant, you will try the system while using only one of the input devices, the Leap Motion controller or the Mouse. After completing the task, you will fill out a questionnaire and rate the system by using a 5-point Likert scale (Strongly Disagree to Strongly Agree) for 13 subjective measures.

This study will take around 10 minutes to try the system and fill the questionnaire. The quantitative data for this study will be analysed and interpreted by applying the statistical analysis.

Participation in this study is voluntary and you can withdraw from it any time without penalty. Also, there are no risks or difficulties in taking part in this study. If you feel uncomfortable at any time, you can take a rest, or withdraw from this study.

All the information and the result will be processed confidentially. The data source will not be published or identified. Your identity will be anonymous and no personal information will be used. In addition, all data will be stored securely for a period of ten years from the date of the study. Then it will be safely destroyed when not needed.

If you have any question or any further quires, please do not hesitate to contact by the below emails.

shaykhah.aldosari@plymouth.ac.uk, davide.marocco@plymouth.ac.uk

I thank and appreciate your fruitful efforts

The researcher

Shaykhah Aldosari

Consent to participate in the questionnaire

1. I confirm that I have read and discussed with the researcher the above Participant Information Sheet for the study. I understand the aims of this research, the questionnaire process, and the data that will be collected.
2. I confirm that I have studied and understood the information detailed in the Participant Information Sheet, have asked questions and received satisfactory answers.
3. I understand that every effort will be made to maintain the confidentiality of my information and the identification details will be changed in the research, to protect identities as much as possible.
4. I understand that all data will be kept securely for a period of 10 years once the study is completed and destroyed once that period has elapsed.
5. I understand that my participation in the study is completely voluntary and I can withdraw without giving a reason and without negative consequences. Also, my right to withdraw my data, even when I conceal my identity, has been fully explained to me.
6. A clear explanation of the complaints procedures was provided, and I have contact details for the researcher and the study supervisor.
7. All potential benefits, risks, or inconveniences were explained to me and I was given a written copy of this to keep for future reference, including the contact details that enable me to get support when needed.

Participation number:

Date:

Signature:

Thank you for taking the time to try the system. We would like to learn more about your experience in using this system. Please take the time to fill out this survey. It should not take more than ten minutes.

- What is your age?

❒ Under 12 years old ❒ 12-17 years old ❒ 18-24 years old ❒ 25 years or older

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- What is your gender?

❒ Female ❒ Male

- What is your current level of education?

❒ Did not complete high school ❒ High school graduate ❒ Bachelor's degree ❒ Postgraduate degree

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- How often do you use the computer?

❒ Rarely ❒ Occasionally ❒ Often ❒ Always

- How would you rate your computer skills?

❒ Poor ❒ Fair ❒ Good ❒ Excellent

- Have you use any simulation learning system before?

❒ Yes ❒ No

<u>Please choose one response for the following statements.</u>

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1. I thought the system was easy to use	1	2	3	4	5
2. I immediately understood the function of the system	1	2	3	4	5
3. I feel that I successfully completed all the tasks	1	2	3	4	5
4. The tasks were easy to complete	1	2	3	4	5
5. The input device helped with my task completion	1	2	3	4	5
6. It was easy to use this device	1	2	3	4	5
7. I feel comfortable using this input device.	1	2	3	4	5
8. I like the interface of this system	1	2	3	4	5

9. It was easy moving from macro-level to micro-level

1	2	3	4	5

10. The information provided for the system is easy to understand

1	2	3	4	5

11. I think the system will be effective in helping me understand the experiments' tasks and scenarios

1	2	3	4	5

12. I would imagine that most people would learn to use this system very quickly

1	2	3	4	5

13. I think that I would like to use this system again

1	2	3	4	5

Appendix F – Pre- and Post-Test Questions in English

Participant Information Sheet

Dear Student:

I am currently a PhD student at Plymouth University, UK. My research is about using the Leap Motion controller in educational systems. The research aims to study the impact of using gesture-based technology, the Leap Motion controller, in education and discovering the effect of the integration of simulation and molecular visualisation as a teaching method. This research presents a chemistry learning system designed for secondary school students.

The aim of this experimental study is to examine the effects of using the chemistry education system that combines simulation and molecular visualisation. The experiment will be conducted in your secondary school and will be supervised by the researcher in cooperation with the teacher.

The study needs four classes of a second grade of secondary school. It will be conducted using two chemistry lessons. The first experiment is about mixing oil with water and the second one is about salt hydrolysis. Two classes will use the traditional teaching method, theoretical teaching and real laboratory. The other two classes will use the presented system with the leap motion controller and the mouse. Two multiple-choice questions testing will be used as pre-tests and post-tests, which are paper tests.

This study will take two weeks. Each lesson will be applied during a week. On the first day of the week, the pre-test will be conducted. Then, on the second day, the teacher will teach the theoretical lesson for all four classes. After that, on the third day, the lesson will be applied in a real lab for one class, and by using the virtual lab with the Leap Motion controller for the second class, and by using the mouse for the third class. While the fourth class will not apply the lesson. On the fourth day of the week, the post-test exam will be taken. The quantitative data for this study will be analysed and interpreted by applying the statistical analysis.

Participation in this study is voluntary and you can withdraw from it any time without penalty. Also, there are no risks or difficulties in taking part in this study. If you feel uncomfortable at any time, you can take a rest or withdraw from this study.

All the information and the test will be processed confidentially and none of the information will be used in any way to evaluate the students. The data source will not be published or identified. Your identity will be anonymous and no personal information will be used.

In addition, all data will be stored securely for a period of ten years from the date of the study. Then it will be safely destroyed when not needed.

The teacher will explain to the students the purpose of the study and to obtain their consent before the study begins. In addition, she must make it clear to them that participation is voluntary and that they have the right to not participate or withdraw at any stage without any penalties. Also, she must explain to them that the information and the exam results will be confidential and that none of the information will be used in any way to evaluate and grade the students.

If you have any question or any further quires, please do not hesitate to contact by below emails.

shaykhah.aldosari@plymouth.ac.uk, davide.marocco@plymouth.ac.uk

I thank and appreciate your fruitful efforts

The researcher

Shaykhah Aldosari

Consent to participate in the experimental Study:

1. I confirm that I have read and discussed with my teacher and the research the above Participant Information Sheet for the study. I understand the aims of this research, the questionnaire process, and the data that will be collected.
2. I confirm that I have studied and understood the information detailed in the Participant Information Sheet, have asked questions and received satisfactory answers.
3. I understand that all the information and the test will be processed confidentially and none of the information will be used in any way for your evaluation and grading.
4. I understand that every effort will be made to maintain the confidentiality of my information and the identification details will be changed in the research, to protect identities as much as possible.
5. I understand that all data will be kept securely for a period of 10 years once the study is completed and destroyed once that period has elapsed.
6. I understand that my participation in the study is completely voluntary and I can withdraw without giving a reason and without negative consequences. Also, my right to withdraw my data, even when I conceal my identity, has been fully explained to me.
7. A clear explanation of the complaints procedures was provided, and I have contact details for the researcher and the study supervisor.
8. All potential benefits, risks, or inconveniences were explained to me and I was given a written copy of this to keep for future reference, including the contact details that enable me to get support when needed.

Participation number:

Date:

Signature:

First experiment questions

Choose the correct answer. If you do not know the answer, choose ‘I do not know’ option:

1. **The oil floats on water because of**
   A. Oil is less dense than water
   B. Water is less dense than oil
   C. Oil has a smaller volume than water
   D. Water has a smaller volume than oil
   E. I do not know

2. **When the oil is dispersed in water as droplets, it forms:**
   A. Emulsion
   B. Solution
   C. Suspension
   D. Heterogeneous mixture
   E. I do not know

3. **The shape of the water molecule is**
   A. Linear
   B. Trigonal planar
   C. Bent (angular)
   D. Tetrahedral
   E. I do not know

4. **Oil is categorized as a:**
   A. Polar molecule
   B. Nonpolar molecule
   C. Negatively charged molecule
   D. Positively charged molecule
   E. I do not know

5. **Water is polar because:**
   A. a slight positive charge on both the hydrogens and the oxygen
   B. a slight negative charge on both the oxygen and the hydrogens
   C. a slight positive charge on the oxygen and a slight negative on the hydrogens
   D. a slight positive charge on the hydrogens and a slight negative charge on the oxygen
   E. I do not know

Second experiment questions

Choose the correct answer. If you do not know the answer, choose 'I do not know' option:

1. **When you add the universal indicator solution to the water, the colour is changed to:**
   A. Yellow
   B. Red
   C. <u>Green</u>
   D. Blue
   E. I do not know

2. **When you add ammonium chloride to the water with the universal indicator solution, the colour is changed to:**
   A. <u>Yellow</u>
   B. Red
   C. Green
   D. Blue
   E. I do not know

3. **When you add sodium nitrate into the water, it gives:**
   A. An acid
   B. A base
   C. <u>A neutral solution</u>
   D. An emulsion
   E. I do not know

4. **When you add potassium fluoride to the water with the universal indicator solution, the colour is changed to:**
   A. Yellow
   B. Red
   C. Green
   D. <u>Blue</u>
   E. I do not know

5. **Water ionizes into:**
   A. <u>Hydroxide ions and hydrogen cations</u>
   B. Hydroxide ions and nitrogen cations
   C. Hydrogen cations

D. Oxygen ions and hydrogen cations
E. I do not know

6. When you add ammonium chloride solution to water, it ionizes into:

A. Hydroxide ions and hydrogen ions
B. Ammonium ions only
C. Chloride ions only
D. Chloride ions and ammonium ions
E. I do not know

7. The acid compound that is formed when the ammonium chloride ionizes in water is:

A. Hydrochloric
B. Ammonium carbonate
C. Ammonium hydroxide
D. Sodium chloride
E. I do not know

8. The equation of basic solution which is formed when the ammonium chloride ionizes in water is:

A. ${NH_4}^+ + H_2O \rightarrow NH_4OH + H^+$
B. ${NH_4}^+ + H_2O \rightarrow NH_3 + H_3O^+$
C. $CL^- + H_2O \rightarrow HOCL + H^+$
D. $CL^- + H_2O \rightarrow HCL + OH^-$
E. I do not know

9. When you add potassium fluoride to the water, it ionizes into:

A. Fluoride ions only
B. Potassium ions only
C. Fluoride ions and potassium ions
D. Hydroxide ions and hydrogen ions
E. I do not know

10. The basic compound that is formed when the potassium fluoride ionizes in water is:

A. Hydrofluoric
B. Potassium hydroxide
C. Potassium carbonate
D. Sodium fluoride
E. I do not know

11. the equation of acid solution which is formed when the potassium fluoride ionizes in water is:

A. $K^+ + H_2O \rightarrow KOH + H^+$
B. $K^+ + H_2O \rightarrow KH + OH^-$
C. $F^- + H_2O \rightarrow FOH + H^+$
D. $\underline{F^- + H_2O \rightarrow HF + OH^-}$
E. I do not know

12. When you add sodium nitrate into water, it ionizes into:

A. Sodium ions
B. Hydroxide ions and nitrate ions
C. <u>Sodium ions and nitrate ions</u>
D. Hydrogen ions and sodium ions
E. I do not know

13. The acid compound that is formed when you add sodium nitrate into water is:

A. <u>Nitric</u>
B. Nitric oxide
C. Hydrochloride
D. Sodium hydroxide
E. I do not know

14. The base compound that is formed when you add sodium nitrate into water is:

A. Nitric
B. Nitric oxide
C. Hydrochloride
D. <u>Sodium hydroxide</u>
E. I do not know

Appendix G – Ethical Approval Application

UNIVERSITY OF PLYMOUTH

25 September 2020

CONFIDENTIAL
Shaykhah Aldosari
School of Engineering, Computing and Mathematics

Dear Shaykhah

Ethical Approval Application

Thank you for submitting the ethical approval form and details concerning your project:

Using Leap Motion API for Educational Games

I am pleased to inform you that this has been approve via Chair's action.

Approval is for the duration of the project. If you wish to continue beyond this date, you will need to seek an extension. Please note that if you wish to make any minor changes to your research, you must complete an amendment form or major changes you will need to resubmit an application.

If you have any queries please let me know

Kind regards

Rebecca Waghorne
Secretary to Faculty Research Ethics Committee

CC Bogdan Ghita

Mrs Jayne Brenen, Head of Faculty Operations, Faculty of Science and Engineering, University of Plymouth, Drake Circus, Plymouth, Devon PL4 8AA T +44 (0)1752 584584 F +44 (0)1752 584540 W www.plymouth.ac.uk