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Identifying the Characteristics of Virtual Reality Gamification for Complex Educational Topics

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Abstract: Multidisciplinary topics in education pose a major challenge for traditional learning and teaching methods. Such topics can deter students from selecting particular courses or hinder their study progress. This study focused on the subject of medicinal chemistry, which is a discipline combining medicine and chemistry. This combination of applied and basic science creates a complex field of education that is challenging to both teach and learn. Chemical and pharmacological principles are typically presented in 2D molecular structures and, recently, 3D molecular models have been utilized to improve the visualization of chemical compounds and their chemical interactions. Contemporary studies have presented Virtual Reality (VR) as an alternative method for improving the learning and teaching of multidisciplinary specialties such as this. However, current educational efforts employing VR offer limited interactivity and a traditional teaching method previously presented in 2D. This reduces students' interest and concentration in the taught subjects. This paper presents the development rationale of a novel VR educational application based on the evaluation of the user requirements by 405 pharmacy undergraduate students. The results informed the development and preliminary evaluation of a proposed VR serious game application, which was deployed in a real-life class environment and evaluated in contrast to traditional teaching methods by 15 students. The derived results confirmed the advantages of VR technology as a learning and teaching tool, in addition to the end-users' willingness to adopt VR systems as a learning aid.

Keywords: virtual reality; gamification; Human-Computer Interaction; education; medical pharmacology; education equity; distance learning

1. Introduction

Subject matter in which in-depth knowledge from two or more distinct scientific backgrounds is required constitute challenging learning and teaching activities. Such courses are typically encountered in scientific subjects where various disciplines intersect, such as courses related to science as applied to medicine or engineering [1,2]. A prime example of such a course is found in the pharmacy curriculum, where chemistry and medicine often intersect. In the medicinal chemistry (MC) specialty, knowledge of advanced chemistry related to the chemical structure of pharmaceuticals is combined with knowledge of the effects of the chemical compounds in the human body [3]. MC provides students with an understanding of drug mechanisms of action and structure-activity relationships (SARs). The study of drug chemistry is considered fundamental to the practice of pharmacy [3].

The complexity of the aforementioned topic, however, deters current science students from pursuing this course, resulting in a gradual decrease in the number of specialist chemists and pharmacologists [4]. In addition, medical and nursing schools have reduced the requirement for attaining specialist pharmacology knowledge, with consequent detrimental effects in the new generation of medical and allied health professionals [4]. To counteract the aforementioned issue, and bridge interdisciplinary knowledge teaching, some traditional methods utilize 2D pictorial representations or have been enriched with 3D plastic or concrete models [5,6]. However, due to their inability to convey complex interactions between the chemical compounds, these methods are gradually being replaced by 3D computer-generated models [7,8]. Nonetheless, the effectiveness of traditional and newly introduced 3D digital models with limited interactivity remains unclear [3,9].

Adhering to the above observations, this study investigated primarily the suitability of interactive and immersive VR environments as teaching applications, designed specifically for the subject of MC. Secondly, this work also considered the use of gamification methods within a VR learning environment. The gamification process is expected to increase students' enjoyment and entice them to constantly improve their scores to achieve different levels within the VR application/game [10]. In this manner, each student is not bound to follow a particular pace or means of learning the molecular structures and chemical interactions. By offering this learning-based adaptivity, it is also expected that the students will be further motivated and thus improve their overall learning performance [10]. Notably, such an application may be further propagated to other similar courses that entail multi-disciplinary subjects as stated previously. To identify the optimal provision of knowledge through a bespoke VR system, it is essential to initially detect the users' requirements and current issues. This could, in turn, inform the design and implementation of a VR system, which will have improved usability and acceptance from the users.

To this end, this paper aims to offer the following contributions.

- This study provides detailed baseline data on students' perceptions of VR technology integration in medicinal chemistry education based on a large cohort (405 students) of survey responses.
- The large cohort results highlighted the students' requirements and acceptance of VR serious game applications for learning and teaching.
- In addition, this study materialized the students' feedback and suggestions in the development of an innovative, proof of concept VR application that may offer an immersive, enjoyable, and user-enticing method of teaching complex information in challenging disciplines such as medicinal chemistry.
- Finally, the paper offers recommendations for future studies based on the results of a preliminary evaluation of the proposed VR application.

The following sections present the related work in the field (Section 2), the structure of the experiment (Section 3), the Experiment Part A: Survey (Section 4), and the Data Analysis and Discussion (Section 5). In turn, the results provided form the basis for the Development of the VR application (Section 6) which is preliminarily evaluated (Section 7). The paper discusses the results and offers recommendations for similar projects (Section 8). Finally, the paper presents the Conclusions and future work (Section 9).

2. Related Work

Chemistry-related disciplines tend to be challenging for a large number of students because they entail abstract models of chemical compounds and reactions, which could be difficult to comprehend by the use of traditional teaching methods. This difficulty may affect students' performance and their self-efficacy [11]. The latter is influenced by the learner's ability to interact and control the learning environment [12–15]. Therefore, this type is best suited to a hybrid approach of teaching and information presentation, which can enable the students to explore and configure the chemical compound models through their own initiative. Additionally, these future applications should be accessible outside the university's laboratories and available at any given time. The latter has previously

been identified as a major obstacle for the student's learning process in other disciplines (i.e., medicine and anatomy), which were found to be heavily dependent on timetabled access to laboratories for training [15–18].

2.1. Current Learning and Teaching Issues in Medicinal Chemistry

As stated above, current teaching approaches utilize primarily traditional education techniques that require the student to translate two-dimensional drawings or graphical representations to a three-dimensional mental structure [19–22]. The mental translation of 2D images into 3D models is also a challenging issue for the majority of students in other disciplines. Previous studies related to the teaching of human anatomy presented similar issues because the medical students found it difficult to visualize the 2D drawings from medical textbooks as real 3D structures related to the human body [13–15,23–25]. The gradual utilization of physical and static 3D models was introduced to alleviate this issue, with limited success, because the physical models had a predetermined interaction that did not reflect the actual properties of the real-life model [26,27] as illustated in Figure 1. The advent of 3D computer technology has enabled, in some circumstances, the development of digital 3D computer models based on physical models. However, the interactivity and ability to customize these models for the needs of different student cohorts has remained an elusive aim [26,28].
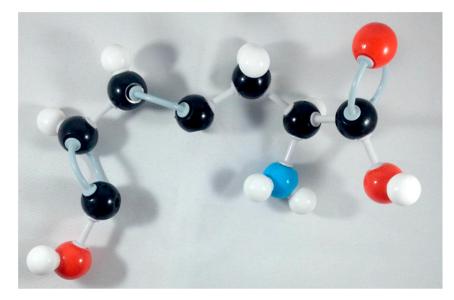

Figure 1. Physical 3D educational modalities for medicinal chemistry courses.

Notably, in chemistry, several desktop 3D applications have been recently developed with the aim of addressing this issue [29–31]. The majority of the commercially available systems have been developed for designing the different chemical compounds and offer a plethora of options for building different molecular structures [32,33]. Nonetheless, these applications are not orientated towards the learning and teaching process required by the students [31].

2.2. Traditional and Future Educational Modalities

Traditional education modalities, such as documents and drawings, have been recently enriched with an assortment of digital elements, such as PowerPoint presentations, videos, digitally produced 2D/3D pictures, and online resources. New technologies and modalities also require an appropriate introduction to the curricula to enable the technology to be accepted by students and teachers alike. In the initial stages, the emerging technologies and novel teaching techniques are typically presented as a complement to the existing approach. Although the modalities and methods used in learning should be complementary, some studies have argued that the instructional methods used in the educational process have a

major impact on learning (i.e., direct instructions versus discovery learning) [34,35]. Further reinforcing this observation, the instructional media (i.e., VR/AR/3D models) improve the learning process as they can offer special features that facilitate and enhance learning, such as exploration of the 3D models without physical constraints [13,35,36].

2.3. Virtual Reality (VR) for Education

Amongst the current emerging technologies, VR technology presents the potential to enhance the education process. Educators from various disciplines have experimented using VR in both the teaching and learning process with encouraging results [13,23,37].

VR learning systems also support learning theories, such as the constructivist theory, which refers to the idea that learners can construct knowledge on their own initiative and through experiencing knowledge information [15,38]. VR systems based on constructivist learning theory provide the 3D experimental environment, which enhances students' ability to solve problems and fosters students' constructive ability [15]. Advancement in emerging visualization technologies enables more users to experience this enhanced form of learning.

Hence, the use of embedded multimedia and VR or Augmented Reality (AR) applications in the education process is rapidly increasing. Students can easily access 3D models and information at their own pace, place, and time, this maximizing the flexibility of the knowledge provision [9,10]. Transitioning to VR learning and teaching applications that can be used through students' home computers and/or VR Head-Mounted Displays (HMDs) also reduces the need for costly under-utilized university facilities. From a teaching outcomes perspective, students who embed VR technology in the learning process are enabled to explore, analyze, and assess information faster and with a higher memory retention rate [12,13,38,39].

Therefore, these students are acquiring additional transferable skills as they become problem solvers, in contrast to passively absorbing information [12,13]. Another aspect of VR training is the ability to complement or completely replace laboratory activities that are problematic to demonstrate and teach, due to insufficient equipment/materials or safety concerns [13,39]. It may also provide a level plane of instruction by eliminating the instructor variation in the depth or breath of teaching [40].

Despite the abundance of benefits provided by the VR systems, however, some drawbacks may affect their usability as a learning and/or education medium. The main hindrances to the introduction of new technology in teaching relates to the users' perception of adopting new technology and whether the technology conforms to the pedagogical aims. As such, the capability of the system to improve student's learning outcomes in the required disciplines, and the acceptance of the particular technology, need to be assessed before embedding VR applications in the current curriculum [12,39,41].

2.4. Relevant Studies

Based on the above observations related to the current learning and teaching issues in chemistry and medicinal chemistry, the following studies were identified as being the most indicative for the utilization of VR/AR technologies in the particular educational fields. Table 1 presents an overview of the papers that present significant progression of 3D, VR, and AR applications from 2007 to 2021, and their main contributions [42–46]. The table also presents the user sample and the main subject of each study. Although numerous studies have been performed for a variety of curriculum courses, as discussed above, the selected papers are explicitly in the areas of chemistry and medicinal chemistry, which align with the interest of this research. Overall, the studies present a common output in which the 3D/VR/AR applications enhance the students' knowledge acquisition and present a viable alternative to current teaching methods. The VR-related studies have been performed with small groups [43,45], whereas only one study used a larger group, of 109 students [44]. The latter was a 3D virtual environment (i.e., non-immersive) conducted at a primary school level. In our study, the first part of the project (i.e., the survey) gathered the results from 405 university students; this sample size is larger than any we encountered in the literature. This

provides a significant advantage for the identification of requirements, preferences, and characteristics that should be incorporated in future VR learning and teaching applications in the examined field. The final study, which involved 250–300 students, used an AR technology that superimposes digital information on real-life environments and, as such, is not an immersive option. Based on the above, the following sections present the structure of two experiments that aimed to address the aforementioned points.

Table 1. Relevant studies in chemistry and medical chemistry presenting VR/AR educational applications.

Reference	Subject	Users	Contributions
[42] (Georgiou et al., 2007)	VR simulation of chemical experiments	N/A	• The use of VR turns learning into an entertaining and easily comprehensible process, and online availability provides free access and use to all Internet users with complete-time and place independency.
[43] (Limniou et al., 2008)	VR 3D structure of chemicals compared to 2D animation	14	• Students comprehended the molecules' structure and their changes during a chemical reaction better than during the 2D animations on the computer's desktop • The equipment currently is a costly investment for a chemistry department for both initial acquisition and maintenance.
[44] (Herga et al., 2015)	3D visualization of virtual laboratory and basic in chemistry education—primary level	109	• Development of a virtual laboratory. The virtual laboratory was found to increase the acquisition of knowledge in the students' sample.
[45] (Suleman et al., 2019)	VR 3D visualization in chemistry education	23	• The use of 3D/VR immersive visualization is categorized as a "good" criterion so that it can be applied in learning to facilitate students in understanding and memorizing material.
[46] (Smith & Friel, 2021)	AR medicinal chemistry education	250–300	• 69% to 88% of the students found the AR models easy to use and 58% to 83% wanted to see more AR models used in future lectures. • A substantial incentive to invest more time and study into the use of AR.

3. Two-Stage Experiment Structure

To design and implement any bespoke VR system and induce the appropriate provision of knowledge through gamification for the medicinal chemistry module, it was deemed essential to identify the users' requirements and clarify their intention of using such technology for learning and teaching purposes. In particular, this paper presents a two-fold experiment that consisted of (a) *a survey of 405 students* and (b) *a preliminary evaluation by 15 students of a prototype VR teaching application* developed following the initial large cohort (405 students) survey, as illustrated in Figure 2. It should be noted that cohort (a) of the 405 surveyed students is not comparable to cohort (b) of the 15 students involved in the preliminary evaluation. The functionalities of the two groups are presented below:
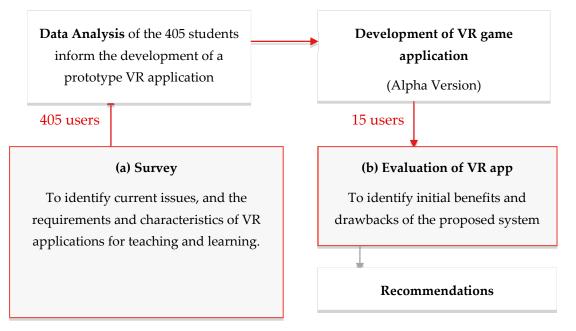
Figure 2. Two-stage experiment structure: (**a**) survey—405 students, and (**b**) preliminary evaluation of prototype VR application.

(**a**) **Survey**: The 405 users were the full cohort in the university that participated in the initial stage of the data collection with regards to the current teaching methods and the potential use of VR games to enhance the teaching process. Section 5 presents the design and results of a survey completed by 405 students that aimed to identify the current issues and the students' expectations for future learning and teaching applications that could employ VR and gamification. Thus, the first part, namely, the survey, was designed to gather more information from all of the students relevant to the medicinal chemistry module. The size of the cohort was the full number of students currently undertaking the course and provided much-needed granularity of results to the data acquisition. These results can be further extrapolated to other similar cohorts across other universities and complex modules. Furthermore, the results were used to identify the characteristics and requirements of future VR gamification applications as set by the students.

(**b**) **Preliminary experiment of the prototype application:** Based on the above results, we developed a prototype VR application, as presented in Section 6, that aimed to address the requirements and points indicated by the 405 students who participated in the survey noted above. This first version of our prototype application was tested with a smaller group (15 students) to identify the potential benefits and drawbacks, and thus lead to further development and testing with a larger group. Testing this early prototype application with 405 students was not be possible due to logistical issues and would not provide any major benefit to the study at this stage [47–49]. Following an iterative process with smaller groups to streamline the application, in the future, we aim to re-evaluate the final version with the original cohort of 405 students.

4. Experiment Part A: Survey

4.1. Method- Rationale

Based on the above, this work aimed primarily to explore the traditional modalities used in pharmacy education in contrast to current VR educational applications related to this subject. In turn, this research aimed to identify students' perceptions of adopting VR technology as a learning medium. The derived data from a large student cohort (405 students), in turn, informed the development of a prototype VR application, which was preliminarily evaluated by a 15 students' cohort. This evaluation's purpose was to confirm the findings from the first, large cohort, and provide the framework for further development of the proposed VR application.

4.2. Research Objectives

The proposed technological modality based on VR and gamification of knowledge employed a 3D medicinal chemistry model to enable the student to visualize in 3D and interact with the chemical structure. The study entailed a questionnaire that aimed to explore the following student responses and aptitudes regarding the traditional teaching methods and current VR applications:

- Explore the instructor teaching methods and the provided source of learning methods used by students at the School of Pharmacy and the evaluation of current learning and teaching method;
- Explore the level of familiarity and use of VR by students;
- Examine students' perceptions of Virtual Reality as a learning and teaching aid in the medicinal chemistry field.

The results were used to develop a VR educational game according to students' needs and requirements to enhance their learning process, as presented in the following sections.

4.3. Participants

The School of Pharmacy at the University of Jordan has an enrolment of approximately 2000 students. These students are required to study three medicinal chemistry courses (a total of eight credit hours). The students are enrolled in one of two programs, either a BSc in Pharmacy or a Doctor of Pharmacy (PharmD). The students study medicinal chemistry in their 4th and 5th years.

The sample of 405 students who participated in this study was the complete cohort enrolled in the Medicinal Chemistry III course during the evaluation period. The particular student cohort was selected because it was familiar with the medicinal chemistry discipline and the current modalities used in teaching this, in addition to the challenges students faced on the particular course.

4.4. Instrumentation

Discussions regarding the current learning/teaching modalities, topics covered, and difficulties encountered by staff in teaching medicinal chemistry and by students in studying the chemical structure of drugs, were carried out using semi-structured interviews. These interviews were conducted with an open framework, which allowed focused, conversational, two-way communication. In addition, the outcome of the analysis of the semi-structured interviews' qualitative data provided feedback on the requirements for the construction of the chemical structure, design of the quizzes, 3D representation, color and design of the class environment, and usability icons.

Several sessions to revise the model by medicinal chemistry professionals were carried out at different stages during the development until a final refined version of a prototype VR application, namely, MedChemVR, was produced.

The result of the conducted interviews showed that the material taught to students is usually difficult to understand, memorize, and apply using traditional teaching and learning modalities (textbooks, presentations, and explanatory images). This is indicated by the results of previous studies that aimed to identify the effectiveness of VR educational applications for the improvement of complex medical teaching [12–18]. In this particular case, the difficulties students experience are mainly due to the abstract and unobservable features of the chemical structures of drugs, which are usually displayed in the 2D format in books and lectures. To acquire the information from the largest possible group of students, a carefully devised questionnaire was administered online, as presented in the following tables. The students volunteered to take part in the study without any financial compensation.

4.5. Survey Design

A.   Survey Structure

As stated above, a total of 405 students completed the survey. The purpose of the questionnaire was to examine pharmacy students' beliefs, perceptions, and outcomes using current teaching and learning modalities. The outcome of this survey and consequent analysis aimed to provide an insight into the acceptance of new teaching methods and systems that would exclusively utilize the emerging technologies, such as VR and, potentially, Augmented Reality (AR).

The survey instrument consisted of 33 questions about the current modalities used for teaching and learning, and the perceptions of adopting new technologies (e.g., VR) as a learning tool, divided into the following categories:

1.   Demographics (Table 2: Questions 1–4);
2.   Current methods used in teaching and learning medicinal chemistry (Table 3, Questions 5–21);
3.   Knowledge in VR (Table 4, Questions 22, 33), and perceptions of technology in education;
4.   VR as a learning medium (Table 5, Questions 24–33).

Table 2. Survey demographics questions.

	Demographic Questions
Q1.	What is your gender? ☐ Female ☐ Male
Q2.	What age group are you in? ☐ <18 ☐ 18–20 ☐ 22–24 ☐ >24
Q3.	Which Pharmacy programme are you in? ☐ Pharmacy ☐ PharmD
Q4.	Your academic year is: ☐1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6

Table 3. Current educational modalities in the medical chemistry: Survey.

	Education Traditional Modalities **By Using Traditional Modalities for Education (Powerpoint Slides, Pictures, Other) Please Answer the Following Questions. Please Answer the Following Questions Where: (1) Strongly Disagree, (2) Disagree, (3) Moderate, (4) Agree, (5) Strongly Agree**
Q5.	The instructors can give each student a chance for practice.
Q6.	The instructors can give students centred communication skills.
Q7.	The instructors are often busy to respond to student needs.
Q8.	The period of explaining the models in the lecture is sufficient.
Q9.	I cannot depend only on using traditional ways of teaching as I use other technologies to enhance learnability (such as YouTube, mobile applications which describe the structures in better ways)
Q10.	Instructor-led class teaching gives more confidence to the students than using alternative technologies.
Q11.	Traditional ways of teaching are boring and I get distracted during the lecture.
Q12.	Drug chemical structures are difficult to understand and memorise using current ways of teaching.
Q13.	I think the current learning tools are flexible enough for training.
Q14.	Understanding the structure-activity relationship (SAR) from the drug chemical structure is easy.
Q15.	Current teaching method helps me identify drug properties based on chemical structure.
Q16.	Visualizing and deriving conclusions from a drug's structure is difficult.
Q17.	Current teaching methods help me to identify activities and side effects from drug structure.
Q18.	The concepts of molecular binding and conformation adopted in vivo are difficult to grasp.
Q19.	I can easily recognise and navigate through the 2D structure of drugs from different perspectives.
Q20.	I feel well prepared for exams.
Q21.	The current teaching and learning modalities are enjoyable.

Table 4. Questions to identify students' previous use of VR.

	Using Virtual Reality Questions
Q23.	I think technology integration into teaching, and learning is very important for students. ☐ No ☐ Yes
Q24.	Using VR will improve the time required to learn the chemical structures in medicinal chemistry. ☐ Yes ☐ No

Table 5. Questions to examine students' knowledge of VR.

	Attitude toward Technology and VR—General Perspectives **For the Following Questions, Please Check the Answer That Relates to Your Attitude about Each Statement Using the Rating Scale below Each Question. Some Questions Will Be about Your Attitude toward Technology in General. Other Questions Will Be Specifically about Your Attitude toward Virtual Reality Technology.** **(1) Strongly Disagree, (2) Disagree, (3) Moderate, (4) Agree, (5) Strongly Agree**
Q24.	I think technology integration into teaching, and learning is very important for students.
Q25.	Using Virtual Reality will improve the time required to learn the chemical structures in medicinal chemistry.
Q26.	I believe there are advantages to using virtual reality technology in our course(s).
Q27.	I believe that virtual world technology provides an immersive learning environment where students can become engaged in learning as we explore the virtual environment.
Q28.	Using the application of 3D models would be easier for me than traditional methods for learning chemical structures in medicinal chemistry.
Q29.	Using virtual models is useful for me because it will increase my knowledge as I can see the 3D structure model of the drug from several viewing positions.
Q30.	The experiment content will help me to better understand and memorize the chemical structure of drugs.
Q31.	Visualizing and rotating the 2D and 3D structure of a drug is helpful in medicinal chemistry studies.
Q32.	It would be helpful to incorporate virtual reality as computerized visual aids during medicinal chemistry lectures.
Q33.	I would consider using virtual reality visual aids to aid my personal studies outside the classroom

B.   Technology Acceptance Model (TAM)

The questionnaire was designed to investigate users' current issues and clarify the users' intentions to use emerging technologies/methods, such as VR and gamification, to improve the learning and teaching experience. For this reason, questions were based primarily on our previous customized *Technology Acceptance Model (TAM)* following previous technology and consumer electronics studies [49–52]. The TAM is an information structure and analysis model designed to predict and measure the adoption of new technologies based on customer attitudes and responses [53–55]. The option of employing a *Structural Equation Modeling (SEM)* approach was also investigated; however, the team consensus was to maintain the same evaluation system as that used in other similar projects that we are currently developing, to provide a standardized platform/method of evaluation.

4.6. Survey Data Validity

The student sample was analyzed using the Statistical Package for the Social Sciences (SPSS). The analysis of the standard deviation (SD) for the questions was performed initially to ensure that the sample (i.e., student cohort) understood the questions and answered them clearly, thereby confirming the validity of the survey. This was deemed essential to avoid random responses to the questionnaire. Notably, a low standard deviation shows that the data is clustered close to the mean value and, as such, the responses are more reliable [56–58]. If the responses presented a highly random approach, the standard deviation would have been high and scattered further away from the mean value. In this project, the standard deviation, as presented in Table 6, was less than one for all of the questions, confirming the survey's validity.

For the questions related to the instructor and the traditional means of teaching (Questions 5 to 21), the analysis indicates the answers were in the acceptance area because the standard deviation was less than one. Similarly, the questions that were related to the use of VR in learning and the advantages of this technology (Questions 24 to 33) were also within the acceptance area.

For questions 22 and 23, 80% of students were aware of VR technology, whereas 47% had used a VR device. These results were particularly encouraging for the employment of VR technology for learning and teaching this course.

Table 6. Standard deviation checking of descriptive statistics.

	Groups of Questions	N	Min	Max	Mean	Std. Deviation
1.	Traditional Modalities for education (Q5–Q21)	405	1	5	3.2	0.43
2.	Attitude toward technology and VR (Q24–Q33)	405	1	2	1.4	0.35
3.	Using VR (Q22–Q23)	405	1.2	5.0	4.3	0.66
	Valid N (listwise)	405				

4.7. Sample Analysis

The analysis of the demographic factors of the sample, including gender, age, program, and academic year were analyzed, and are presented in detail in Appendix A. The results showed that the majority of the students in the cohort were females (352 versus 53 males), which translates to a sample breakdown of 87% female and 13% male.

The majority of participants (91%) were aged between 22 and 24 years. The student sample was segmented into three categories of students' age: (a) 18–22, (b) 22–24, and (c) students older than 24 years of age. Students taking Medicinal Chemistry III courses are either enrolled in the Pharmacy or Doctor of Pharmacy (PharmD) program. In the particular cohort, 236 students (58.3%) were enrolled in Pharmacy and 169 students in PharmD (41.7%).

Among the 405 students, 87% were in their fifth year and 10% in their fourth year, as presented, and a small percentage (3%) undertook this module in year 3 or 6.

4.8. Cronbach's Alpha

Cronbach's alpha is a value that is commonly calculated when multiple-item measures/values of a concept are used [59]. Typically, when the Cronbach alpha value exceeds 70% (0.7), then the reliability of the produced data can be confirmed.

To confirm the reliability of this survey's produced data, the Cronbach alpha was calculated, and offered encouraging results. Specifically, the result was 0.812, which means that the derived data from the 29 questions meets the required reliability level. Additionally, the level of internal consistency for the scale with this specific sample was more than 80% and, as such, the results of this study were accepted and can be generalized.

In turn, Table 7, depicts the results of Cronbach's alpha if a question has been deleted. The results show a level of internal consistency between 78% and 80% and, as such, the results remain acceptable and can be generalized to the overall student population.

4.9. Correlation

The correlation between the data and the relationship between the traditional data and the new proposed technology VR is presented in Table 8. Notably, the relationship between the traditional and new VR technology is positive, with an approximate percentage error of 1%. The latter reveals that a VR educational system is expected to achieve the desired learning and teaching goals.

The analysis of questions 24 to 33 presented in Table 9 shows that all of the answers were within the acceptance area (standard deviation is less than one) and therefore can be acknowledged.

Table 7. Cronbach's alpha—item total statistics.

Questions	Scale Mean If Item Deleted	Scale Variance If Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha If Item Deleted
Q5	96.44	107.257	0.333	0.806
Q6	96.43	106.558	0.382	0.804
Q7	97.19	113.121	0.045	0.820
Q8	96.59	106.763	0.313	0.808
Q9	95.89	108.127	0.265	0.810
Q10	96.16	108.112	0.315	0.807
Q11	96.10	110.411	0.166	0.814
Q12	95.88	112.022	0.102	0.817
Q13	96.94	108.430	0.326	0.806
Q14	96.67	108.361	0.266	0.809
Q15	96.49	108.325	0.301	0.808
Q16	96.43	112.682	0.088	0.816
Q17	96.58	107.938	0.338	0.806
Q18	96.44	111.296	0.193	0.811
Q19	96.95	109.017	0.263	0.809
Q20	97.04	108.661	0.272	0.809
Q21	97.13	108.530	0.263	0.809
Q24	95.22	107.432	0.481	0.802
Q25	95.46	105.150	0.588	0.797
Q26	95.41	105.678	0.570	0.798
Q27	95.52	106.196	0.550	0.799
Q28	95.46	105.061	0.545	0.798
Q29	95.47	105.185	0.550	0.798
Q30	95.48	105.641	0.546	0.799
Q31	95.45	105.287	0.569	0.798
Q32	95.51	104.577	0.616	0.796
Q33	95.66	105.055	0.535	0.798
Q22	98.54	116.080	−0.090	0.816
Q23	98.21	115.669	−0.042	0.816

Table 8. Correlation—item total statistics.

Valid	Frequency	Percent	VR	Using VR
Traditional	Pearson Correlation	1	−0.051	0.206 **
	Sig. (1-tailed)		0.152	0.000
	N	405	405	405
VR	Pearson Correlation	−0.051	1	−0.092 *
	Sig. (1-tailed)	0.152		0.032
	N	405	405	405
Using VR	Pearson Correlation	0.206 **	−0.092 *	1
	Sig. (1-tailed)	0.000	0.032	
	N	405	405	405

*. Correlation is significant at the 0.05 level (1-tailed). **. Correlation is significant at the 0.01 level (1-tailed).

Table 9. Descriptive statistics.

Questions	Scale Mean If Item Deleted	Min	Max	Mean	Std. Deviation
Q24	405	1	0.333	4.52	0.750
Q25	405	1	0.382	4.28	0.802
Q26	405	1	0.045	4.33	0.783
Q27	405	1	0.313	4.22	0.767
Q28	405	1	0.265	4.28	0.864
Q29	405	1	0.315	4.27	0.848
Q30	405	1	0.166	4.26	0.816
Q31	405	1	0.102	4.29	0.815
Q32	405	1	0.326	4.23	0.813
Q33	405	1	0.266	4.08	0.880
Valid N (listwise)	405	1	0.301		

5. Survey Data Analysis and Discussion

This study aimed to explore student tendencies, as identified and presented in the previous section. The data analysis and discussion of each of the above tendencies are presented in the following subsections.

5.1. Current Teaching Modalities and Student Satisfaction

The primary objective was designed, in part, to examine the level of student's satisfaction with current teaching modalities. This section consisted of 17 questions that asked students about current modalities used in medicinal chemistry education and their satisfaction with them. The results of the most interesting questions are discussed in this section. Firstly, the participants were asked if they are given a chance to practice in the classroom and only 42% agreed (13% and 29% "Strongly agree" and "Agree", respectively) (Question 5). Then, participants were asked if instructors can provide centered communication skills (where students take a much more active and independent role [60] (Question 6); 43% agreed (11% and 32% "Strongly agree" and "Agree", respectively).

Students were asked if they can depend on using traditional modalities of teaching only; 65% of participants answered that they cannot depend only on using traditional means of teaching and that they use other technologies to enhance their learning (such as YouTube and mobile applications that describe structures in better ways). Nevertheless, 53% of participants believe that the instructor-led knowledge provision gives more confidence to the students than using other technologies. However, 57% of participants consider the traditional ways of teaching boring, and that they became distracted during lectures.

When students were asked if drug chemical structures are difficult to understand and memorize using current means of teaching, 65% of the students agreed (35% and 30% "Strongly agree" and "Agree", respectively) (Question 12). Furthermore, only 18% of students considered the current learning tools flexible enough for training. Moreover, only 35% of the students thought that understanding the structure-activity relationship (SAR) from drug chemical structures is easy (Question 13).

The following four questions (Questions 14–17) aimed to measure the students' ability to obtain the skills expected from this course, which involve using the chemical structure as a source of information, including a drug's pharmacological activity, side effects, and physicochemical properties that can affect its stability, compatibility, storage, and drug-to-drug interactions.

When the students were asked whether understanding the SAR from the drug chemical structure is easy (Question 14), only 35.5% agreed (8.6% and 26.9% "Strongly agree" and "Agree", respectively). In addition, only 42.5% of the students agreed that current teaching methods help them to identify drug properties based on chemical structure.

However, 43.2% of the students agreed that visualizing and deriving conclusions from a drug's structure is difficult. Only 38.2% of the students believed that current teaching methods help them identify drug activity and side effects from the drug structure (Question 17).

Only 22% of students agreed that they can easily recognize and navigate through the 2D sketch of the structure of drugs from different perspectives (Question 19). Evidently, this issue has been previously highlighted in multiple studies, in which the majority of users were unable to create a mental 3D model from 2D images [13,61,62]. This issue appeared to be a major deterrent for various activities in which the users struggled to visualize proposed 2D architectural blueprints or 2D web images [45,46]. In the particular complex environment of medical chemistry structures, this issue is amplified exponentially.

Moreover, only 18% of students felt that they are well prepared for exams (Question 20), a result again attributed to the difficulty of translating the written information and the 2D images into a 3D set of information. The aforementioned results were reinforced by the answer to the last question in this section (Question 21), as only 19% of students found the current teaching and learning modalities enjoyable.

It can be noted from the students' answers that, although the students trust the knowledge provide by the instructors, they still cannot solely depend on it to understand

and visualize the drug structure. Therefore, they use other learning-enhancing technologies. Furthermore, students find drug chemical structures difficult to understand and memorize. This further impacts their ability to navigate the 2D structure of drugs from different perspectives [63–65]. Most students perceive the current means of teaching boring, and become distracted in the lectures. In addition, explaining the drug activity and SAR from the structure was difficult when they relied on current teaching methods.

5.2. Student Knowledge of VR Technology

As expected from the student cohort, the majority of students (80%) had heard about VR technology. However, Question 23 revealed that 52% of the students had not previously used a VR device. Nevertheless, the results showed that the majority of users had heard about VR and approximately half had previously used a VR device. These findings may facilitate integrating a VR educational system into the learning process for this particular group [31,64–66].

5.3. Students' Perception of VR as a Teaching Aid

Students were in favor of technology integration into education; 90% of students believed that technology and education integration is very important for improving their accessibility and interaction with the educational material. Notably, this is a "native technology generation", that is expected in the near future to maximise the use of emerging and immersive technologies in every aspect of their daily lives [65].

The students also believed that using VR in their courses will have many advantages, as 87% stated. Furthermore, 84% of the students believed that VR will save the time and effort required to learn the chemical structures in the medicinal chemistry course.

The immersive learning environment that VR provides enhances the students' engagement in the learning process. In addition, as indicated by a majority of 86% of the participants, the students believed the application of 3D models would be easier than traditional methods, and will increase their knowledge in learning chemical structures in medicinal chemistry.

Additionally, 85% of students believed that the content of the experiment in a VR environment will help them to better understand and memorize the chemical structure of drugs, and would be helpful to incorporate virtual reality as computerized visual aids during medicinal chemistry lectures.

Accordingly, 79% of students intended to use VR visual aids to support their studies outside the classroom when it is available.

These findings are in line with previous studies [12,13,31–34], which also commented on the advantages of VR integration into education. Previous studies also noted that technology acceptance is directly proportional to the user's perceived advantage, particularly when VR and 3D emerging technologies are employed [45]. Furthermore, the successful integration of VR into the educational system is directly dependent on the willingness of the users to accept the technology [12,14].

5.4. Exploring VR Teaching Application Options

The derived results, as stated above, highlighted the students' interest in VR technology. It was also evident that traditional teaching modalities were not adequate for presenting complex information in a clear and timely manner. The outcome of this study was the development of the VR classroom in the MedChemVR game that satisfies students' needs and requirements.

6. Development of the VR Educational Application

6.1. VR Application Rationale

The aforementioned results and feedback provided by the student cohort indicate a requirement for a shift from the teaching methodology that is currently used. Additionally, these results are indicative of the growing necessity for a more technologically

appealing and accessible method for the new generations of students. The latter cohort and future generations are accustomed to different methods of information presentation and interaction, because they are the "digital natives" population in terms of emerging technologies [65–67]. Based on the above results, an educational VR system can be considered a welcome addition to the educational curriculum and teaching methods.

The particular characteristics of such an application, as highlighted by the survey results, should entail: (a) simple and fast interactivity with the VR environment; (b) relevant educational material and imaginative visualization that can support the 3D understanding of the structures by the students; (c) gamification that can entice the students to learn through play; (d) immersion in the VR application through appropriate equipment and relatable 3D environments; and (e) accessibility and affordability based on the use of existing equipment and networking capabilities. The latter may further enhance the immersion and presence of the user within the digital environment and the communication with other students online. The aforementioned characteristics were embedded in the final MedChemVR application, as presented in detail in the following sub-sections.

In addition, such a VR application should aim to provide the students with affordable, flexible, and accessible functionalities. Further post-survey feedback of the students also revealed a potential requirement for the gamification of such an application. The latter entails a competitive game approach to improve the interest of the students in the long term. The repetitive mode and the different levels of a game typically galvanize players and entice them to gradually improve their performance to achieve a better level within the game. This action further enhances the competitive spirit between peers and ultimately provides an enjoyable conduit for knowledge acquisition [67].

Furthermore, these methods (i.e., VR and gamification) have been previously investigated by educational gamification studies, which revealed better student performance and long-term knowledge retention [14,15,68,69].

Unlike physical ball-and-stick models, a VR application can be a reusable system of high and consistent quality because there is no deterioration of the quality of the model upon use, which often happens with physical models. Furthermore, as the VR application can be downloaded on smartphones, students' access is not limited to predetermined teaching hours or space (i.e., laboratories) [13].

Moreover, due to their recent development, affordable VR tools offer a more cost-effective solution in contrast to physical models for both students and educational institutes. Based on the above results and observations, this study aimed to materialize the students' responses and subjective feedback into a fully functional VR application that would entail the gamification aspect and all of the main requirements indicated. As such, it was deemed necessary to develop and embed the following features in the system:

- Simplified 3D models for functional and interactive visualization to minimize the hardware requirements;
- Smartphone accessibility and 3D/VR provision, thus minimizing hardware requirements;
- Explanatory information for understanding the 3D structure of drug molecules;
- Functional visualization of the 3D structure;
- Simple and fast HCI for the interaction with the 3D structure in space;
- Provision of information for the atoms and the functional groups of the different drug molecules;
- Enhancing the students' spatial understanding of the molecular structures through VR interactive positioning of the atoms in selected molecular scaffolds;
- Gamification of the above learning activity against Non-Player Characters (NPCs) and their peers;
- Provision of additional material for both pharmacological and SAR information for each drug structure.

6.2. VR Application Design

The aforementioned system requirements provided the framework for the development of a bespoke VR application, namely, MedChemVR, and stemmed from the survey results and suggestions of the 405 students, as illustrated in Figure 3. The system presented in the following sections was designed to be affordable, simple, and accessible. In turn, the proposed VR application utilized both immersive VR and gamification methods aimed at providing the students with a unique experience that entices them to pursue the required knowledge on this subject in a simple and enjoyable manner.
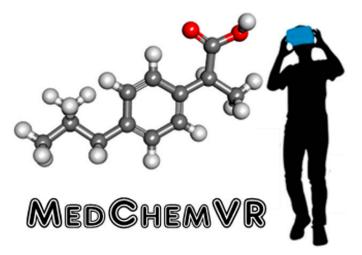

Figure 3. Screenshot of the introduction screen of the prototype MedChemVR application.

For the development of the proposed VR application, this work considered the following five key points to cover all the aspects required, as related to the system's educational value, enjoyment, and accessibility.

6.3. Educational Context and Imaginative Visualisation

The educational context of the application followed a consultation process with the university staff teaching the course. The consultations included a description of the subject being taught to the students and its purpose and importance. As part of the curriculum, the students are required to memorize the chemical structures of several drugs (approximately 60 in each course); the provision of this material was deemed essential for the VR application.

The details of these structures, such as the general scaffold, atoms, functional groups, and colors representing different elements within the compounds, were clarified in the VR application, following the traditional teaching methods. The imaginative visualization of the educational context was also an important element that was required to be captured by the system and presented to the students in a manner that could enhance their spatial awareness and understanding of the three-dimensionality of their course.

6.4. Interface Design

The design of the system's interface employed both the students' survey feedback and the curriculum-related information provided by the specialist university staff based on curriculum particulars. To provide interactivity, both with the 3D molecular structures and the environment, this work opted for a direct manipulation interface [68,69]. The latter method was used successfully in previous VR educational and commercial applications [12,45,55,70]. Direct manipulation and direct action with the virtual objects or menu symbols enable the users/students to extend the real-time interaction with the digital objects within the VR environment. The different interaction options are rotate, add, remove, zoom in/out, and highlight, which enables the students to pick and change the type and position of the objects within the VR environment. To simplify the hardware provision,

the interaction within the VR system was enabled by a typical mini-joystick/controller, which is available with any HMD that utilizes a mobile phone, as a screen, as presented in Figure 4.
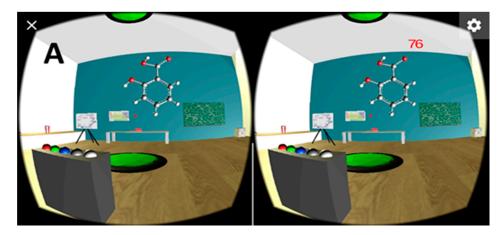

Figure 4. Screenshot of the VR application as seen in a smartphone.

Unlike traditional modalities, the provision of an immersive and fully interactive VR environment provides the ability to explore and perceive in three dimensions the structural differences and interactions of the chemical compounds. This was highlighted by the students as a major drawback of the traditional teaching methods and the current teaching aid materials.

6.5. 3D/VR Visualisation

The 3D elements of the VR application were primarily the drug molecules of the selected group's chemical compounds and the 3D classroom interior. To avoid student distraction by photorealistic 3D environments, it was deemed ideal to reduce the visual realism and focus mainly on the interaction with the 3D molecules. Three-dimensional visualization aimed primarily at functionality was used previously in medical projects that required the user to focus on identifying the visual information and accelerated the knowledge acquisition process [12,13]. Photorealistic depiction of structures was useful only in cases in which the 3D visuals presented information related to texture, color, and form, which is relevant to the identification of medical issues, such as breast cancer, heart anatomy, inguinal canal anatomy, and other medical training contexts [12–17].

In this case, the structural positioning of 3D models does not require significant visual detail. In turn, the simplicity of the visuals, in this case, present the advantage of lower requirements for the hardware. As such, the students are not constrained by high-specification equipment (e.g., VR headsets or smartphones) to view and interact with the VR application, as can be seen in Figure 4. The 3D molecules were designed with the ChemDraw Professional 16.0 software, which enabled the software developers to generate and visualize the 3D ball-and-stick models of small molecules from 2D sketches [30,56]. Both the classroom environment and the 3D chemical models of the drug molecules were exported to Unity3D games' engine for the development of the VR space and interactions
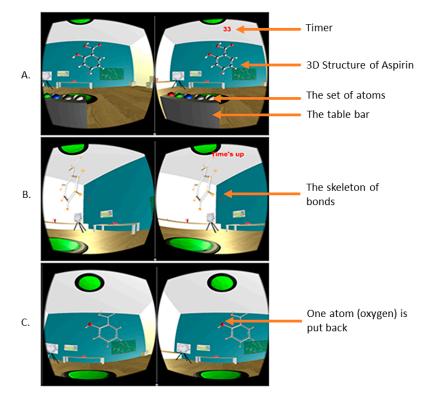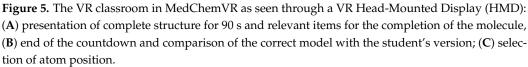
6.6. System Gamification

The provision of the educational material was extremely important; however, previous studies highlighted that, overall, the gamification of training and educational material improves a student's ability to understand and retain the acquired knowledge [71,72].

However, the gamification process of any educational material is highly dependent on the relevance of the material to the overall syllabus and the connection that the gamification subject has to the rest of the course material and the desired training goals [73–75]. For this purpose, the proposed VR application entailed three distinctive scenarios of gamification to

entice the users to experience the VR space and play timed games aimed to challenge their knowledge in the field. The three scenarios are presented in detail below and illustrated in Figure 5:

- First, the system provides a plethora of 3D colored spheres representing different atoms, positioned randomly on a table. The user is requested to build a particular chemical compound by memory within a specific time limit.
- A second scenario was developed to compare the constructed chemical structure to the correct drug chemical structure, with the aim of determining whether the structure is correct.
- A third scenario was designed to be applied in the training session. In this case, the elements' spheres disappear 60 s following the start of the game.

Figure 5. The VR classroom in MedChemVR as seen through a VR Head-Mounted Display (HMD): (**A**) presentation of complete structure for 90 s and relevant items for the completion of the molecule, (**B**) end of the countdown and comparison of the correct model with the student's version; (**C**) selection of atom position.

Furthermore, the VR application employed an assortment of different sounds (audio icons) associated with each move to motivate the player and attract his or her attention [76–78]. The system was equipped with three main pages, namely, the start page, play mode, and quiz page.

The play mode interface introduces the student to the interface by showing subclasses divided according to the chemical class to which drugs belong. For visualization of the 2D format, as shown in the interface by clicking on the 2D structure, the student is guided to the VR classroom. Figure 4 demonstrates the VR classroom in the MedChemVR game as follows:

1. The system allows the student to examine, navigate, and review the structure for 60 s in both the play mode and the quiz mode.
2. When the time has expired, the spheres representing the atoms disappear and the skeleton of the bonds is displayed.

3. The student can start playing by adding atoms to the skeleton to rebuild the molecular structure of the drug.

In play mode, the system accepts the sphere only if the right atom is placed in the right position.

In quiz mode, the system accepts the sphere regardless of the correct answer and, if the student places all of the atoms in their right positions, s/he achieves a full score. If any of the atoms are placed in the wrong position, the student scores zero. The interaction with the game engine and the user's performance is recorded and analyzed to provide bespoke feedback. Based on these results, the level of difficulty can be altered through a Training Content Management (TCM) system to better suit each participant, and support each student until a successful outcome is reached. The structure of the system operation is presented in Figure 6 below.
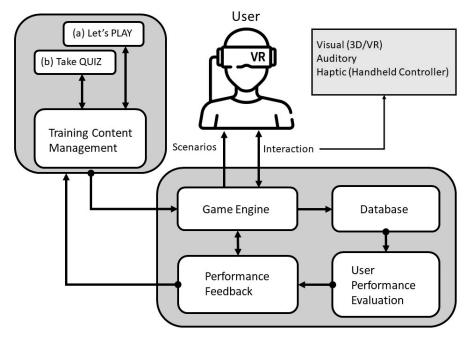

Figure 6. Diagram presenting the structure of components and operations of MedChemVR.

6.7. System Accessibility and Immersion

To facilitate a system that is cost-efficient and simple to use, the Unity3D game engine was employed as the basis for the development of the VR application. Accessibility was also deemed to be essential for the development of a system that can be experienced outside the laboratory environment and with minimum equipment requirements.

Thus, the VR application was developed for smartphone devices, thereby enabling the students to use their own mobile phones to power and view the application through an inexpensive HMD or other hardware, as seen in Figure 7. The immersion in the class environment was achieved through a full 3D model of a typical class that surrounds the user.

The model positions the user at a 1:1 scale within the VR environment because immersion requires a match between the user's proprioceptive feedback of body movement and the interactive operations that can be achieved in the real world [78–80]. The positioning of the camera representing the visual cone of the user within the VR environment is positioned following each user's height. The environment is supported by surround audio offered directly to the user via headphones, thus further enhancing the immersion. The selection of/interaction with objects within the VR environment is achieved by the use of handheld controllers typically provided with any VR HMD.

Figure 7. A student uses her smartphone and a low-cost HMD device to use the MedChemVR educational game during the evaluation process.

7. Experiment Part B: Prototype MedChemVR Application—Preliminary Evaluation

To identify the benefits and drawbacks of the prototype VR application, it was deemed essential to perform a preliminary study aiming to identify the efficiency and acceptability of the VR proposed application.

7.1. Participants

This study involved the participation of 15 students of the same cohort that provided the overall feedback and offered an initial appraisal of the proposed VR application. The selection of 15 students, rather than the full cohort of 405 students, was intended to simplify and accelerate the acquisition of feedback that, in turn, can be used to improve the iterative development process of the following application versions.

In addition, previous studies suggested that preliminary evaluations can use up to five users, and acquire valid and useful data for further development. The students were asked to perform a series of tasks typically performed as part of an exercise in the traditional teaching environment.

7.2. Experiment Instruments

A quantitative evaluation was based on a survey consisting of 22 questions divided into three sections, namely: (a) the student information (questions 1–4) in an identical format to that of the survey; (b) users' overall perception of the game as a learning tool (questions 5–11); and (c) students' attitude towards MedChemVR (questions 12–22). The points covered by the questions in the evaluation questionnaire are detailed in Table 10. A five-point Likert scale was used to record responses, ranging from strongly disagree to strongly agree.

7.3. Experiment Design

During the experiment, the users were asked to access the main interface and initially select the play mode, "Let's Play", followed by the quiz mode, "Take a Quiz".

The play version was designed primarily to engage the student in a playful process of experimenting with the molecules provided in the VR environment.

Table 10. Evaluation questionnaire for the MedChemVR application.

Please Answer the Following Questions Where: **(−2) Strongly Disagree, (−1) Disagree, (0) Moderate, (1) Agree, (2) Strongly Agree**	
Q5.	Drug chemical structures are easy to understand and memorise using the MedChemVR game.
Q6.	I think the MedChemVR learning tool is flexible enough for training.
Q7.	Understanding the Structure-Activity Relationship (SAR) from the drug chemical structure is easy.
Q8.	Visualizing and deriving conclusions from a drug's structure is easy.
Q9.	I can easily recognise and navigate through the 3D structure of drugs from different perspectives.
Q10.	I feel I will be well prepared for exams.
Q11.	The MedChemVR game is an enjoyable learning tool
Q12.	I think MedChemVR game integration into teaching and learning is very important for students.
Q13.	Using Virtual Reality saves the time required to learn the chemical structures in medicinal chemistry.
Q14.	I believe there are advantages to using virtual reality technology in our course(s).
Q15.	I believe that MedChemVR provides an immersive learning environment where students can become engaged in learning as we explore the virtual environment.
Q16.	Using the application of 3D Models would be easier for me than traditional methods for learning chemical structures in medicinal chemistry
Q17.	Using virtual models is useful for me because it will increase my knowledge as I can see the 3D structure model of a drug from several viewing positions
Q18.	The experiment content helps me to better understand and memorize the chemical structure of a drug.
Q19.	Visualizing and rotating 2D and 3D structures of a drug is helpful in medicinal chemistry studies.
Q20.	It would be helpful to incorporate virtual reality as computerised visual aids during medicinal chemistry lectures
Q21.	I think my academic achievement will be enhanced by embedding MedChemVR as a learning tool.
Q22.	I would consider using virtual reality visual aids to aid my personal studies outside the classroom.

In contrast, the quiz version was designed to test the students' acquisition of knowledge and offer a standard medium of evaluation for the student's knowledge retention in subsequent future experiments [81]. This was considered an essential element of the proposed VR application, in contrast to the majority of other VR applications that primarily offered an alternative to lectures by demonstration of building the molecular structure in 3D environments. The quiz mode followed previous work on VR medical teaching applications for anatomy and pathology, which was successfully tested based on the questionnaires of the license exams conducted by the Membership of the Royal College of Surgeons (MRCS) [12,13,18].

During the play mode, the students were taught course material related to specific chemical compounds and structures. In turn, the students were asked to activate the quiz mode, which was designed to challenge the student's memory and spatial ability during the reconstruction of the molecular scaffolding and molecule positioning. The timing for both play and quiz modes was appropriate for experiencing the system, while maintaining the examination requirements, and was typically 120 s per activity. However, the time can be altered by the experimenter if this is considered to be helpful for a student.

a. During the quiz mode the scaffolding had no atoms assigned. The student should select the atoms and position them on the structure as originally taught during the play mode.

b. The system accept the student's choices and positioning regardless of the atoms' color. Once the atoms are positioned and confirmed to be in place, they cannot be changed. The atoms are changeable only in the play mode.

c. If any of the atoms are wrongly positioned in the scaffolding, the system informs the student to "Try again!".

d. If all of the atoms are correctly positioned, the system confirms the positive outcome by presenting the message "Success".

e. To reduce the student's anxiety and replicate similar activities from mainstream games, the student can quit the game at any point, and exit the VR classroom by pointing the cursor of the remote handheld controller at the fire exit door. This action will return the user to the main menu.

All of the above activities were investigated by the second cohort of 15 students prior to completing the post questionnaire. The results of this evaluation are presented in the following section.

8. Evaluation Results, Discussion, Recommendations, and Limitations

A.   Evaluation Results

The preliminary evaluation results were analyzed, and concise and informative results were obtained regarding the functionality and acceptability of the proposed system for the students. The reliability of the produced data was confirmed because the Cronbach alpha value was 0.829. For the span of questions between Q5 to Q22, the value of the mean indicates that "agree" and "strongly agree" dominated the responses of the students; the returned values varied between 0.4 and 1.6. The mean values for the responses of the 15 evaluation participants to the key questions used for calculating Q25 and Q26 (Q5, 6, 7, 8, 9, 13, 16, 17, 18, and 22) are illustrated in Figure 8. These values ranged between 0.4 and 1.6, indicating answers of "agree" and "strongly agree" were most dominant among responses, and the answers of the sample were within two standard deviations of the mean. The values of the standard deviation varied between 0.63994 and 1.24212. A negative binomial (N.B.) frequency distribution indicates the percentage of answers for each category.
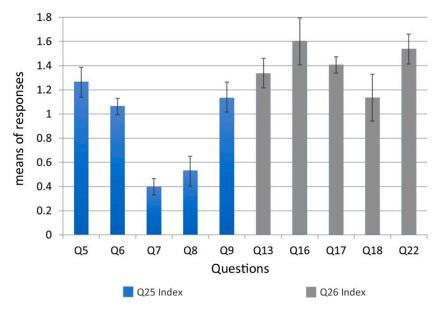

Figure 8. Graphical representation of the means of responses to key questions in the evaluation questionnaire.

In turn, the correlation tests showed the following:

- An index called Q26 (MedChemVR as a learning tool was computed by adding Q13, Q16, Q17, Q18, and Q22 and an index called Q25 (attitude toward MedChemVR) was computed by adding Q5, Q6, Q7, Q8, and Q9 to test the relationships between the two indices. It was calculated to be 0.667 and found to be significant at the 0.01 level.
- The computed correlation of Q25 with variables Q13, Q16, Q17, Q18, and Q22 was highly correlated. To define the relationship between the values, the study calculated Pearson's r value, which can range from −1 to 1. The negative values indicate a negative linear relationship between the values, whereas 0 specifies no linear relationship, and 1 indicates a perfect positive linear relationship. In this case, the Pearson value ranged within 0.306–0.73, which is desirable and indicates a positive relationship between the values of the question responses. Only Q13, Q16, and Q17 were highly correlated with the other group. In addition, Q13 and Q17 were significant at the 0.01 level, and Q16 was significant at the 0.05 level.

- The computed correlation of Q26 with variables Q5, Q6, Q7, Q8, and Q9 resulted in a Pearson value that ranged between 0.126 and 0.639, in which only Q6 and Q9 were significant at the 0.05 level.
- Additional regression analysis was performed excluding the questions that showed poor correlations.
- The analysis of variance (ANOVA) showed that the five questions (Q13, Q16, Q17, Q18, Q22) together explained any changes in the dependent variable (Q25), where the F-value was 5.362 (>3.84, significant at the 0.01 level). Furthermore, Q25 was affected by the independent variables (Q6 and Q9), where the F value was 12.433, significant at the 0.001 level. Their *t*-value was above 1.97.

B.   Discussion and Recommendations

The consequent evaluation of the system's variation with a larger cohort of students provided similar results. The gathered information can be used in the future stages of development for optimizing and enriching the student learning experience [82,83]. Other studies that employed VR teaching applications in similar science subjects also supported the findings from our previous work [42–46,83].

Although this study offered the contributions stated in Section 1, the topic requires further examination to assess users' perception of integrating VR technology as a learning medium in medicinal chemistry education.

1. This study provided detailed and substantive baseline data on students' perceptions of VR technology integration in medicinal chemistry education. However, the experiment should be performed in other courses that contain complex and multidisciplinary modules.
2. Conducting qualitative interviews with a larger sample of students will enrich the outcome of further studies by providing in-depth insights on best practices for VR technology integration.
3. A similar study should be conducted to evaluate faculty members' attitudes and perceptions of VR technology as a teaching medium.
4. Further research needs to be conducted to determine the strategies for providing faculty members with effective training and professional development.
5. Student outcomes in learning using the MedChemVR game versus traditional methods should be assessed.
6. Evaluation by pharmacy students covering several aspects should be conducted to ensure usability and enjoyability.
7. Measurement of the impact of this game on the achievement of students in their exams would be useful for system optimization and refinement.

Additional general recommendations to more effectively enable VR technology integration into teaching and learning are provided for future studies, as stated below:

1. Students should be educated about technologies in learning and teaching activities via seminars and hands-on training.
2. Capacity building is needed to transform the ordinary classroom into a VR medium and to train staff on the use of technology in the classroom.
3. Student awareness should be increased regarding the use of technology and its impact on learning, and the amount and quality of the knowledge gained, which will be reflected in their grades and achievements.
4. The awareness among the teaching staff of technology integration into education should be increased via staff emails, learning management systems, seminars, and posters

C.   Limitations

The purpose of this study was to explore the current teaching modalities for medicinal chemistry and students' knowledge of VR, and to examine students' perceptions of adopting VR technology as a learning medium in medicinal chemistry education. However, certain limitations should be taken into consideration. This study was conducted with

participants located in one university covering a particular geographic region. Results should be interpreted carefully until further data from similar groups of participants in other educational establishments and regions are obtained. Additionally, this study was performed before the current pandemic and, as such, the data gathered at that time may not fully reflect the current requirements. Given the technological exposure experienced by the students during two years of remote lectures, assessments, and communications, it would be of interest to repeat this two-part experiment, and contrast the updated results with those presented in this article.

9. Conclusions

The paper presented a study of a large student cohort (405 students) to identify the current demand, acceptability, and suitability of VR and gamification technology for the teaching of multi-disciplinary courses such as medicinal chemistry. Medicinal chemistry was selected because it currently poses a significant challenge to chemistry and medicine students due to its complexity and the abstract notion of the chemical compounds and their interactions.

The derived results supported the VR technology and suggested that this approach can improve chemistry learning and the teaching process. The major benefit of VR is the ability to transfer the learning process to a simulated environment that is not limited to place or time, while enabling the students to gradually experience, and develop their knowledge of, the subject.

The second part of this study aimed to provide succinct yet informative results based on the evaluation of the alpha version of a custom VR application (MedChemVR) that was developed based on the students' feedback. This application was evaluated by 15 students. The preliminary results were encouraging and consistent with those of the initial large-cohort student survey. This system was designed and tested before the current pandemic, and its aim was to complement the main teaching channel of face-to-face in-class teaching. However, it is unclear how such an application can support students' needs for learning and if it is able to fulfill the role of the main teaching method in the future. As such, a tentative plan for future work entails the development of additional scenarios and a scoring process that can further improve the gamification of the system, and its evaluation as the main teaching conduit. Furthermore, future studies will aim to utilize different evaluation and analysis methods to investigate and further verify the initial results. For this purpose, we will attempt to use Structural Equation Modelling (SEM) rather than the existing questionnaire based on the TAM structure. Finally, we anticipate performing a full cohort comparative study in which the final version of the MedChemVR system will be contrasted to the teaching methods that are traditionally used for medicinal chemistry.

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Appendix A

The analysis of the demographic factors of the sample, including gender, age, program, and academic year are presented in the following tables. Specifically, Table A1 presents the gender percentages in the group. The results show that the number of females was 352 versus 53 males in the sample, with percentages of 87% (female) and 13% (male).

Table A1. Gender distribution.

Valid	Frequency	Percent	Valid Percent	Cumulative Percent
Male	53	13.1	13.1	13.1
Female	352	86.9	86.9	100.0
Total	405	100.0	100.0	

The majority of participants (91%) were aged between 22 and 24 years. Table A2, shows the age distribution within the sample. The students' sample was segmented into three categories of students' age: (a) 18–22, (b) 22–24, and (c) students older than 24 years.

Table A2. Age distribution.

Valid	Frequency	Percent	Valid Percent	Cumulative Percent
18–22	16	4.0	4.0	4.0
22–24	372	91.9	91.9	95.8
>24	17	4.2	4.2	100.0
Total	405	100.0	100.0	

Table A3 shows the program in which the students are enrolled. Students taking Medicinal Chemistry III courses are either enrolled in the Pharmacy or Doctor of Pharmacy (PharmD) program.

Table A3. Course enrolment distribution.

Valid	Frequency	Percent	Valid Percent	Cumulative Percent
Pharmacy	236	58.3	58.3	58.3
PharmacyD	169	41.7	41.7	100.0
Total	405	100.0	100.0	

Table A4 presents the academic year distribution of the students that select the particular module. Among the 405 students, 87% were in their fifth year and 10% in their fourth year; a small percentage (3%) selected this module in years 3 or 6.

Table A4. Academic Year Distribution.

Valid	Frequency	Percent	Valid Percent	Cumulative Percent
3	1	0.2	0.2	0.2
4	41	10.1	10.1	10.1
5	354	87.4	87.4	87.4
6	9	2.2	2.2	100.0
Total	405	100.0	100.0	

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