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The Value of Virtual Reality Technology in Embryology Education; Objective and Subjective Outcomes

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ABSTRACT

Medical education is witnessing a rapid evolution of learning tools, fuelled by the emergence of novel information technologies. Virtual reality (VR) technology and three-dimensional (3D) visualization is gaining popularity in this field. Embryology, a branch of the anatomical sciences, is an area where there is room for the utilization of such technology. The representation of the human embryo within a VR environment could complement current teaching aids and overcome existing shortfalls. The impact of this on the educational outcome, however, has not been extensively evaluated. This paper describes a comparative study evaluating the benefit of VR technology in embryology teaching, by comparing it to an existing tool, namely two-dimensional (2D) images of the human embryo, and a subjective evaluation of students' views regarding the use of VR to learn the embryology course material. The results showed that VR enhances embryology education when assessed both in a subjective and objective manner.

KEYWORDS
Embryology, Medical Education, Virtual Reality, 3D model, Human Embryo, Comparative Study, Questionnaire

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1. INTRODUCTION

The study of the human embryo as part of the medical education curriculum is vital in the understanding of the development of the anatomical structures, and the pathogenesis of congenital anomalies [1]. A sound knowledge of embryology is essential in most fields of medicine, for example, obstetrics and radiology[1]. In most medical schools, embryology is taught as part of the anatomy course, the content of the curriculum is largely theoretical, and there is a tendency towards reducing the number of lectures designated to this subject, as well as the utilization of blended and online learning strategies [2-3].

The current teaching methods employed in classroom presentations sometimes struggle to convey a comprehensive representation of the morphogenesis of the human embryo, and its 3D spatial arrangement [4]. This has led to the recognition of the need to make use of computer based technologies to aid in the reform of the educational process, and to overcome the current system's shortfalls within the limited lecture time allocated to this subject, to ensure effective learning and good recall of the learned material [5-6]. This study aims to investigate whether the application of VR technology and 3D demonstration of the human embryo has the potential to enhance the learning process of students in the embryology course in two ways: firstly, objective evaluation of the learning outcome by comparing the performance of two groups of students in a short quiz, where on group used the VR Embryology System to learn the material, while the other attended a lecture using 2D images, and secondly, assessing the subjective views of the students that were exposed to the VR system with regard to utilizing it for learning the course content.

2. BACKGROUND

Embryology remains an important subject in medical education. It is required to understand clinical situations in specialties such as obstetrics and pediatrics, to better understand relevant subject such as gross anatomy, to improve the health and well-being of the developing fetus by aiding the understanding of teratology [7].

Changes in the organization of medical school embryology curricula across most medical schools has led to the emergence of the need to update the ways in which this subject is taught to students. The lecture time allocated to the embryology course is becoming less and it is still being taught in a theoretical manner, with little or no laboratory exposure. It has been widely recognized that to overcome this issue, novel technologies in the teaching process, such as VR, should be implemented, as well as making use of online resources [2,3,5,6]. The best methods for teaching embryology should be practical and use animations that improve the students' three-dimensional visualization of the complex structures and their dynamic evolution [7].

Virtual reality technology offers a multitude of advantages to the educational process, as it facilitates for immersion, increased motivation, and interactivity, thereby enriching the learning experience for the user [8]. When VR is used to facilitate learning of anatomical structures, the learning process can be performed on virtual models and specimens, overcoming pollution, loss, and restricted resources available to the learner. Furthermore, by combining a number of features including visual and audio effects, animations and added texts, VR technology can transform the sometimes-boring traditional lectures into a more stimulating and satisfying experience [9].

This can add further benefits in term of enhancing certain aspects such as more realistic representation of the 3D structures and their continuously changing arrangements throughout embryo development, that are sometimes hard to imagine and grasp if traditional tools are used [4].

The use of a multimedia approach including visual aids such as images, movies and animations in medical education also has the potential to improve integration between basic and clinical sciences [10].

Several anatomical and embryological educational tools using VR technology have been developed to aid the understanding of a number of structures, such as the heart [11], pelvis [12], inner ear [13], and the human embryo [14-15].

These tools show great potential as a valuable addition to the currently used educational methods [16], it is however important to properly evaluate its actual effectiveness and impact on the learning process.

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In most studies comparing the improvement in knowledge through the implementation of technology-assisted learning methods to traditional ones, the former were found to be equal or superior to the latter, however it was not determined which of the technology-assisted methods was the best, or what the best use of such methods was [17].

Although important, ideally the assessment of the usefulness of VR technology in embryology education should not be limited to the subjective views of the users, but should involve more objective assessments such as a short quiz to measure the impact on knowledge gain.

Alfalah *et al*, evaluated the willingness of students to accept the introduction of VR technology into the embryology course[15], and found that students perceive this type of educational tool to be of potential benefit to their learning, based on their previous knowledge with regard to this type of technology, which encourages its introduction into the curriculum [18]. Furthermore, Liu *et al* found that the combination of traditional laboratory exposure with a virtual laboratory enhances experimental teaching of histoembryology [19].

Interestingly, VR technology has been objectively evaluated in terms of learning outcome by Nicholson *et al*, by comparing two groups of students who were exposed to a web tutorial either including or not including a dimensional model of the ear in a virtual reality setting [20], followed by a series of 15 quiz question to evaluate their knowledge, and demonstrated a significant difference in the mean scores in favour of the group exposed to the VR model [13], whereas Alfalah *et al* assessed VR technology subjectively with regard to enhancing user satisfaction and results demonstrate that the use of this type of intervention in anatomy education is significantly satisfactory for the user [15,20].

In this context, and to evaluate the educational value of VR technology in the field of embryology in particular, this study was designed to assess in both a subjective and objective manner whether virtual reality can enhance the learning outcome for undergraduates studying this subject.

3. METHODS AND MATERIALS

3.1 Study design

This research used a comparative study to evaluate the educational value of virtual reality technology when used for learning the content of the embryology course taught to medical students in their first year of undergraduate study, compared to the traditional methods that are currently used. The outcome was measured through completing a 10-item quiz after exposure to the learning material by both groups. This was then followed by the completion of a questionnaire by the group exposed to the VR system to evaluate the participants' subjective views regarding this educational method.

Ethical approval for this study was granted by the Institutional Review Board of the Faculty of Medicine in the University of Jordan.

3.2 Participants

Participants were recruited from first year medical and dentistry students in the University of Jordan (Amman – Jordan), that have not yet been exposed to the embryology course which is usually taught in the second semester of the first year, to evaluate the effect of first-time exposure to the material without prior knowledge.

The study was explained to 200 students and 80 students volunteered to participate. No compensation was given for participation.

Participants were divided into two groups of 40 members each to participate in one of the two arms of the study.

3.3 Materials

A VR embryology system was designed taking into consideration the requirements of the study. The focus was on the surface anatomy development of the embryo, in addition to the development of some of the vital organ structures such as the heart and brain. A 3D model of the stages of the embryo's development from fertilization all the way through the

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first ten weeks was constructed from scratch referring to 2D images and models, using Maya software, following which it was imported into Unity software to create a virtual environment in which the user can either watch an animation that takes them through the stages of development sequentially, or access each stage individually. Each stage contains a 3D representation of the embryo which the user can manipulate in a multitude of ways (rotation, moving, zooming in and out) to achieve proper 3D visualization of all aspects of the external structures of the embryo, in addition to a brief description and relevant information, and a number of animations regarding vital structures of the embryo (Figure 1 a and b).

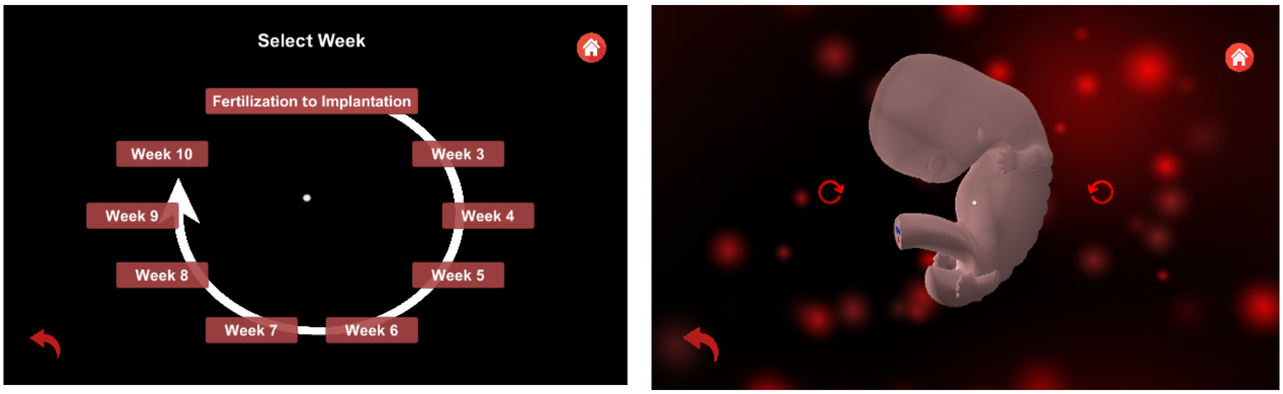

Figure 1: a. week by week developmental stages of the human embryo can be accessed by the system user through this interface. b. Week 6 stage of human embryo development.

For the other arm of the study, a PowerPoint presentation was designed including 2D images of all stages of the embryos development similar to the content of the VR system but without the 3D features, and the same information and descriptions were included.

3.4 Procedure

Two groups of 40 students each with no previous knowledge of the embryology course material were randomly assigned to either a presentation of the VR system (Figure 2) of 45 min duration, or a lecture using traditional teaching methods lasting 45 minutes as well, namely a power point presentation including 2D images and information identical to the content of the VR system (Figure 3).

Figure 2: Student using the VR Embryology System.

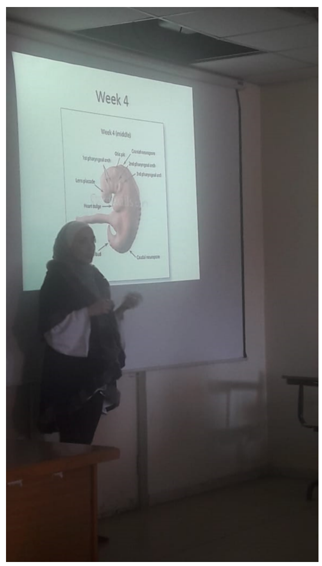

Figure 3: Embryology lecture using traditional teaching method (Power Point Presentation with 2D images)

Following the presentation each group was asked to participate in a short (20 minutes) multiple-choice question (MCQ) quiz consisting of 10 questions derived from the content of the presentation, to objectively evaluate the amount of information retained by the users (Figure 4 and Figure 5).

Figure 4: VR System Group students answering the MCQ quiz

Figure 5: Traditional Lecture Group students answering MCQ quiz

Furthermore, the group that were exposed to the VR system were asked to complete a questionnaire to evaluate their subjective views regarding this learning methods, regarding three aspects; firstly, the system's efficiency and usability, secondly, its flexibility, enjoy ability and user acceptance, and finally, the learning benefits of the system.

4. RESULTS

Statistical analysis of the quiz and questionnaire results was performed using SPSS version 18.

4.1 Quiz Analysis

Both student groups completed a 10 question MCQ quiz after exposure to either the VR embryology system or the traditional lecture utilizing 2D images. For each question the participants were given 5 choices from a to e, with one correct answer for each question. Assuming the passing score to be 5 out of 10 correct answers, table 1 shows a simple comparison between the number of students passing the quiz, and the total numbers of correct answers in each of the two groups. From the data in Table 1, the percentage of students passing increased from 42.5% in the traditional group to 90% in the VR group. Measuring the performance according to the total numbers of correct answers, it was found to increase from 46.25% in the traditional group to 58.25% in the VR group.

Table 1: comparison between the two student groups with regard to the number of students passing the quiz, and the total number of correct answers per group.

	N	Range	Min	Max	Mean	Std. Deviation	Variance
Traditional Lecture Group	40	6	1	7	4.63	1.659	2.753
VR System Group	40	6	3	9	5.83	1.394	1.943

Table 2 shows more detailed descriptive statistics for the quiz scores in both groups, including the mean scores for both groups, which increased from 4.63 in the Traditional Lecture Group to 5.83 in the VR System Group.

Table 2: Detailed descriptive score analysis for both student groups

	Students Passing Quiz	Correct Answers	Wrong Answers
Traditional Lecture Group	17	185	215
VR System Group	36	233	167

Detailed analysis of the scores for each question is represented in figure 6 and figure 7. It shows the number and percentage of correct vs wrong answers for each question, for the traditional and VR group, respectively.

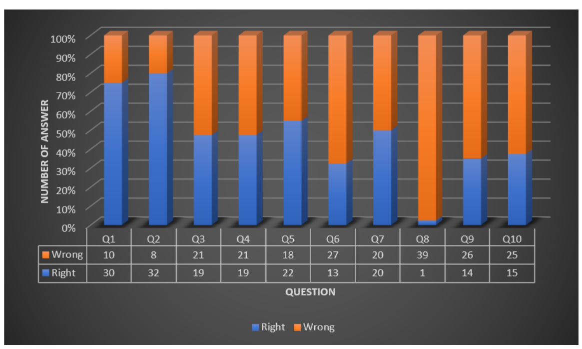

Figure 6: Percentage of correct vs wrong answers in Traditional Lecture

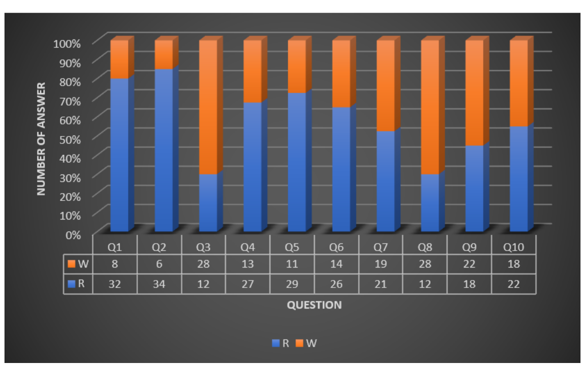

Figure 7: Percentage of correct vs wrong answers in VR System Group

As demonstrated above, the number of correct answers generally increased for the VR system group's responses. Question 1 and 2 were concerned with the fertilization process (Q1: How many sperm cells penetrate the zona pellucida at the time of fertilization, Q2: What part of the sperm fuses with the nucleus of the ovum). For both questions the number of correct answers increased for the VR group (from 30 to 32, and 32 to 34, respectively), indicating that the students achieved a better understanding and visualization of this early phase of development.

Question 3 to 5 were concerned with the early structural development of the embryo (Q3: regarding limb bud development, Q4: regarding somite development, Q5: regarding the development of the upper and lower limbs). The number of correct answers increased from 19 to 27 for question 4, and from 22 to 29 for question 5, indicating that the students gained a better understanding of these events when using the VR system. However for question 3, which was concerned with the timing of limb bud development, the correct answer count was higher for the traditional lecture group, indicating that VR technology was not particularly beneficial when it comes to recalling the timing of certain events.

Question 6 to 10 were concerned with further development of specific structures and organs (Q6: development of neural pathways, Q7: development of the eye, Q8: sequence of development of surface anatomy of the head, neck and limbs, Q9: development of hand and feet plates, Q10: development of the heart). The number of correct answers for all five questions were higher for the VR system group responses as demonstrated in figure 6 and 7. A significant rise was noted in question 8, which examined the students' knowledge of the chronological sequence of development of the surface anatomy of the embryo, which points towards that this concept is better grasped when utilizing VR technology.

Figure 8 compares the numbers of correct answers for each question in the two student groups. It shows that there is a significant difference in the number of correct answers between the two groups in favour of VR system users, more so in the questions regarding the structural development of the embryo's organs and surface anatomy structures, where 3D visualization is required (Q4-6, 8-10).

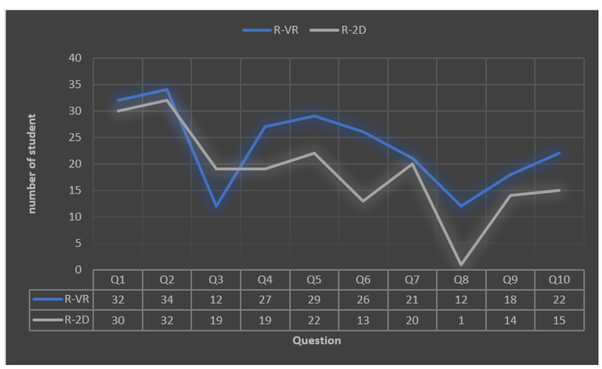

Figure 8: Comparison of number of correct answers per question for both groups

One-sample t test for the scores of both groups was performed and relevant data and results are shown in Tables 3 and 4.

The null hypothesis assumes that there is no difference between quiz performance of students exposed to the traditional lecture (which is the currently used method, and therefore this group's mean is considered the known population's mean) and those exposed to the VR system, but according to the 95% Confidence Interval of the Difference the value is not significant, meaning that the null hypothesis is rejected leading to the acceptance of the alternative hypothesis, indicating that the performance of the students in the VR group is superior to those in the traditional group.

Table 3: One-Sample statistics for students' scores in each group

	N	Mean	Std. Deviation	Std. Error Mean

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Traditional Lecture Group	40	4.63	1.659	.262
VR System Group	40	5.83	1.394	.220

Table 4: One-Sample Test for students' scores in both group

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Traditional Lecture Group	17.629	39	.000	4.625	4.09	5.16
VR System Group	26.430	39	.000	5.825	5.38	6.27

4.2 Questionnaire Analysis

Questions	Min score	Max score	Mean	Standard deviation
Efficiency and Usability				
1. The system is easy to use	3	5	4.68	0.526
2. The functions provided in the system allows free manipulation of the embryo model	3	5	4.57	0.636
3. The system contains information relevant to the embryology course	3	5	4.22	0.832
4. The system makes learning time efficient	2	5	4.42	0.712
Flexibility, Enjoyability and User Acceptance				
5. I would find it useful for such a system to be incorporated into the embryology course	3	5	4.70	0.564
6. The system offers learning flexibility of the embryology course	3	5	4.45	0.677
7. The system is enjoyable to use	3	5	4.72	0.599
8. I would use the system to supplement available learning methods if it was available	3	5	4.60	0.591

Learning Benefits				
9. The system helps me to memorise and retain information well	1	5	4.07	0.971
10. The system helps me to understand the 3D structure of the embryo	4	5	4.65	0.483

The demographics of the student group were analyzed according to the gender of the participants, and their faculty. Participants were 47.5% female and 52.5 % male. 40% were medical students and 60% dentistry students.

The questionnaire consisted of ten questions, grouped into three groups according to the assessed system characteristics as follows: Efficiency and Usability (questions 1 till 4), Flexibility, Enjoyability and User Acceptance (questions 5 till 8), and Learning Benefits (questions 9 and10) (Table 5). Responses were scored on a five-point scale as follows: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree.

Table 5: Mean Score and Standard Deviation for each question (1-10) of the questionnaire

The mean score for each of the 10 question, as well as the mean score for each question group, was in the range between 4 and 5, indicating a positive attitude of the students towards all areas measured in this questionnaire (Table 5).

The standard deviation was checked for each question (table 5), and for each of the three question groups (Table 6) in order to assess whether the participants understood all the questions and answered accordingly. Standard deviation was found to be less than one for all questions and question groups. This indicates that for questions in all three groups, all answers were found in the acceptance area.

Table 6: Score and Standard Deviation for each of the three sections of the questionnaire

	N	Min	Max	Mean	Std. Deviation
Efficiency and Usability	40	4	5	4.48	.483
Flexibility, Enjoy ability and User Acceptance	40	4	5	4.62	.427
Learning Benefits	40	3	5	4.36	.588

Cronbach's alpha after analysis was found 0.805 which indicates that the reliability level, i.e. level of internal consistency is more than 80%, meaning that the results can be accepted and generalized.

5. DISCUSSION

The previous results reflect the evaluation of the VR embryology system in two different ways. First, the system was evaluated objectively, by the means of comparing the outcome if identical quizzes undertaken by two groups of 40 students each, after either using the VR system and its contents to learn the given embryology material, or attending a presentation in traditional lecture format utilizing 2D images of similar content to that of the VR system.

The performance of students within the VR system group was significantly superior to that of the students in the traditional lecture group. The mean scores were 5.83 versus 4.63, respectively. The pass rate was 90% for the VR group and 42.5% for the traditional lecture group. This is consistent with previous similar studies that showed that this learning method has the potential to improve the learning outcome for the user (Nicholson *et al.*, 2006).

This suggests that the use of VR technology as an educational tool to aid teaching and learning of the embryology course material would have a positive impact on the learning outcome, as it seems to improve the students' understanding and retention of the material, hence improving their performance in the assessment. The VR system was then evaluated subjectively by assessing the students views via a ten-question questionnaire with regards to three domains: Efficiency and Usability (questions 1 till 4), Flexibility, Enjoyability and User Acceptance (questions 5 till 8), and Learning Benefits (questions 9 and10).

Students demonstrated a positive attitude towards using this educational tool to aid them in studying the embryology course material, as their responses to all three question groups were in the acceptance area with good internal consistency and statistically significant positive correlations between them, thereby confirming was has been demonstrated in previous studies (Alfalah *et al*., 2019b).

Study Limitations:

This study was performed with a limited number of participants, from two faculties within one university. Studying the effect of this educational intervention on a wider target population in multiple centers is required to confirm the findings of this research on a larger scale. We recognize that in reality, students will not use just one or the other modality in their learning process, as in addition to the official material, there is an abundance of online resources that students tend to access, including videos and animations, and the VR system in this context aims to complement rather than replace current educational resources. However, in this study the effect of knowledge accumulation from using other resources was eliminated by the fact that students had no previous exposure to the course material, and no previous knowledge of the content of the presentation or lecture. Therefore, the scores of the quiz reflected purely the knowledge gained from the presentation at the time of intervention.

The depth of knowledge gained by the students during this study is not comparable to that of a whole embryology course, as the presentations merely represents an introduction to the material and focuses mainly on surface anatomy rather than internal structures. Nevertheless, it can be considered indicative of the value of the implication of such an educational intervention on a wider scale.

6. CONCLUSION

This study shows that the use of virtual reality technology to teach and study embryology has the potential to significantly impact on the educational process in a positive manner. Previous studies have already pointed towards the important role this novel technology in medical education, particularly in subjects such as anatomy and embryology. However, the significance of this study stems from the combination of objective as well as subjective evaluation of the same tool.

This resulted in the conclusion that the use of virtual reality in embryology education actually improves the learning outcome when objectively measured, as compared to the traditional lecture-based learning with the aid of 2D images, as mean and per question scores and pass rates were significantly higher for the group that used this method to learn the material.

On top of the measured benefits, the students also subjectively viewed this method of learning to be efficient and usable, found it to be enjoyable and flexible with good acceptance from the user, and felt that it added to the educational process by offering a number of benefits, namely good 3D visualization and understanding, and efficient information retention. Both methods of evaluation therefore demonstrate that the use of VR technology in embryology education can provide a significantly valuable tool that improves the outcome of the learning process objectively and subjectively.

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