The Integration of Digital Techniques in Engineering Education: A Case Study to Evaluate Student's Motivation and Performance

Mohamad Iyad Al-Khiami*, Martin Jaeger, and Sayed Mohamad Soleimani

***Abstract*—The importance of a paradigm shift in the current traditional teaching strategies is becoming of high importance. Integrating disruptive technologies into undergraduate civil engineering students can improve their performance and motivation levels. Students were assessed on their ability to identify mistakes in a concrete design developed using Autodesk Revit®. The students were divided into three different groups and assessed using three different media: 2 dimensional plans (2D), 3 dimensional models (3D) and virtual reality (VR). The results have shown that 3D and VR students managed to score 54.9% and 62.5% respectively. 2D students scored 20.5%. This shows a substantial difference between VR and 3D relative to the 2D group. From the surveys conducted, it was also perceived that students found 3D and VR methods more motivating than the 2D traditional method. Spearman correlation also indicated a positive and medium to strong correlation between the level of motivation and performance of VR students. The results show that VR is a valid alternative to conventional methods of teaching. This study is part of an ongoing research effort related to utilization of VR in engineering education.**

***Index Terms*—Head mounted display (HMD), motivation, performance, 2D plans (2D), virtual reality (VR)**

I. Introduction

Traditional teaching methods have been perceived as rather boring and disengaging. It requires students to use their memory based on the knowledge they have gained during their lectures to address assessments [1]. According to Soliman *et al*. [2–5], "Such learning approach is active from the instructor side but passive from the receiver (student) student side."

The need for a paradigm shift from the current traditional teaching strategies to more innovative pedagogy through the integration of technological and digital advancement is a necessity. Innovative pedagogy can be introduced using various teaching techniques. Moreover, the implementation of technological tools can further support this shift [3].

Undergraduate studies in Civil Engineering have been lacking the use of technology. Several technological software and equipment including building information modeling (BIM) software and virtual reality (VR) can play a vital role in improving the performance and motivation of students.

Civil Engineering students usually lack the experience of actual construction sites and are unable to differentiate and distinguish between what is considered as industry practice and what is not. Computer aided design (CAD) software such as Autodesk AutoCAD®, has been the most common instrument of design. Using the basic tools of AutoCAD®, 2D plans of various architecture, engineering and construction (AEC) disciplines are created.

Unfortunately, students find it difficult and rather boring when interpreting and understanding these plans, specifically in tasks that include clash detection, mistake identification and design review.

Using disruptive technologies such as VR technology has the potential of improving the students' capacity and motivation towards learning, interpreting, and understanding 2D plans. The use of VR through head mounted display (HMD) which has become technologically advanced and economically feasible [4]. The ability to visualize buildings in 3D, conducting a walk through, allows students to conduct further investigation and examination of the structure. Such advancement is possible using BIM tools and real time rendering software such as Autodesk Revit® and Enscape® respectively.

II. Research Question

The aim of this study is to investigate the potential advantages of utilizing VR technologies for undergraduate civil engineering students regarding performance and motivation related to mistake identification.

III. Literature Review

It is argued by Alizadehsalehi *et al*. [5] that BIM is considered a very effective tool in 3D presentations of structures and that the integration of a model developed using BIM software with VR using HMD further augments the experience and creates an immersive virtual environment. Dayarathna *et al*. [6] confirmed the ability of VR headsets in the immersion of users within the environment.

A study was conducted on fifty-nine students where a VR module for queuing theory was developed to improve their learning outcomes and motivation. The results confirmed that the implementation of VR technology has enhanced the student's learning and understanding of the queuing theory, it also confirmed that VR positively influenced the student's motivation towards learning [6].

A similar study was implemented on 18 local school students in which they used HMD VR equipment to navigate around a model of an unidentified school. The results showed

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that most students found that the VR and augmented reality (AR) technologies had a significant impact in understanding the spatial concepts [7].

Furthermore, a study conducted on 21 undergraduate and graduate civil engineering students comparing VR aided learning, instructor aided learning and video aided learning for laboratory courses, revealed that VR aided learning was the most favorable method in improving the learning outcomes [8]. The results also agreed with Dayarathna *et al*. [6] when it comes to the overall motivation of students.

It is also reported that virtual environments across 68 studies, when integrated in all educational levels improved the performance, visual and observational skills, engagement, and motivation levels of students [9].

However, considering concrete design and mistake identification in structural plans, the impact of VR on students' performance and motivation is still unclear.

IV. Methodology

To examine the advantages of VR and 3D modeling in comparison with the traditional 2D plans, the following assessment tool was developed as per the work break down structure shown in Fig. 1. First, using Autodesk Revit®, a building structure consisting of a foundation level, ground floor, first floor and a roof top was designed using the structural components provided. The building was designed based on engineering best practices. Construction vehicles, equipment and tools were added to the design to increase the real-life appearance of the model.

The model was then altered by incorporating twelve different structural mistakes that must be identified by students as a performance indicator.

2D plans where then prepared using the sheet composition panel of Autodesk Revit®. Nine different sheets were exported with all dimensions and annotations representing the whole structure. The sheets consisted of the foundation plan, ground floor plan, first floor plan, roof top plan, all elevations and building sections. Construction site equipment and tools were hidden from the 2D plans directing the focus towards the building design only.

Fig 2 shows the 3D model in Enscape®, a real-time rendering plugin compatible with Autodesk Revit® that was used to transfer the model into a more realistic and immersive 3D model providing the freedom of navigation when compared to Autodesk Revit® navigating tools. Enscape® also has the capacity and compatibility with HMD VR sets.

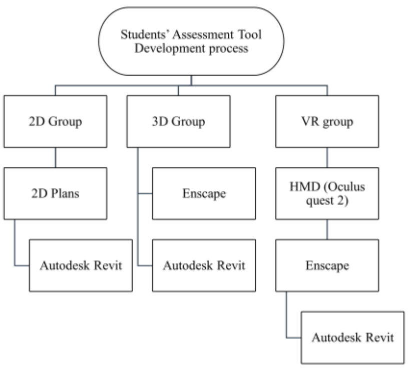

Fig. 1. Flow chart showing the assessment development.

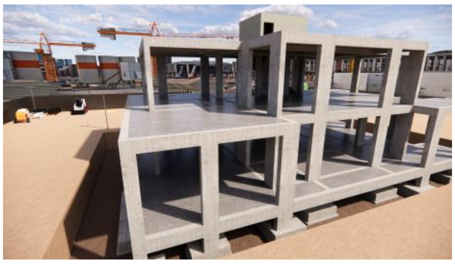

Fig. 2. 3D model in Enscape®.

Since this research is exploratory and specifically targets undergraduate civil engineering students, a non-probability sampling technique was conducted in collecting the sample [10]. The reason is to limit variables and ensure that all students have had the same engineering education obtained from the institution. Second year undergraduate civil engineering students in a concrete structure course were then randomly categorized into three groups, 2D, 3D and VR.

Each student was given a group letter and a group number to distinguish each student per group. The group letter and number must be written in all surveys conducted.

Table I shows the socio-demographic data from a survey that was carried out amongst all thirty-three students prior to the assessment, collecting information regarding age, gender, Grade Point Average (GPA), and experience with 2D Plans, video games, VR and construction site.

TABLE I: Socio-Demographic Data

Socio-Demographic Data			Scale
Demographic Questions	Q1	Age	16–18 19–21 22–24 25–27 >27
	Q2	Gender	Male Female
	Q3	GPA (out of 4.00)	<2.00 2.00–2.49 2.50–2.99 3.00–3.50 >3.50
Knowledge Based Questions	Q1	VR experience	No experience Slight experience Moderate experience Very experienced
	Q2	Video Games experience	No experience Slight experience Moderate experience Very experienced
	Q3	2D plans reading experience	No additional plans read 1–5 plans 6–9 plans >10 plans
	Q4	Number of construction site visits	No visits 1–5 visits 6–10 visits > 10 visits

The 2D group were then given the nine sheets and were put in an assessment like scenario. Using a highlighter, they were asked to highlight any mistake they see in the plans within fifteen minutes.

Similarly, the 3D and VR groups were asked to complete the assessment solo with the instructor. Both the 3D and VR groups were given a five-minute tutorial on how to use the software and controllers. The HMD used for the VR group was the Oculus Quest 2.

For all three groups, the number of identified mistakes, wrongly identified mistake categories and time was recorded.

Finally, students were asked to complete the Intrinsic Motivation Inventory (IMI) survey of the Interest/Enjoyment subscale consisting of seven questions as shown in Table II based on a Likert scale from 1–7 investigating students' motivation levels, where 1 is defined as "Not at all true" and 7 defined as "Very true" [11].

TABLE II: INTRINSIC MOTIVATION INVENTORY SURVEY

Question	Interest/Enjoyment Subscale
1	I enjoyed doing this activity very much
2	This activity was fun to do
3	I thought this was a boring activity
4	This activity did not hold my attention at all
5	I would describe this activity as very interesting
6	I thought this activity was quite enjoyable
7	While I was doing this activity, I was thinking about how much I enjoyed it

All surveys were prepared and completed using google forms.

The following explains the flow of students during the assessment for:

- 2D group
  1. Students enter the assessment venue
  2. 2D plans are distributed amongst the students
  3. Stopwatch starts (15 minutes)
  4. Students start identifying mistakes
  5. 2D plans are handed back to instructor
  6. 5 minutes break is given
  7. Students asked to complete the IMI survey
  8. Students leave the venue
- 3D/VR groups
  1. Student enters the assessment venue
  2. A quick tutorial is given on using the software and controllers on a sample project
  3. Stopwatch starts (15 minutes)
  4. Screen recording and assessment starts simultaneously
  5. 5 minutes break is given
  6. Students asked to complete the IMI survey
  7. Students leave the venue

The scores were collected from the hard copies and transferred to excel for analysis.

V. RESULTS AND DISCUSSION

A. Socio-Demographic Survey

Table III and IV show the socio-demographic responses of all thirty-three students. The responses revealed that the 2D, 3D and VR groups all had an average of 60% female and 40% male students. The dominant age group amongst the 2D, 3D, and VR group is 19–21. While the 2D group had no students above the age of 27, the 3D and VR groups had 2 and 1 student respectively.

When considering the GPA, the groups revolved around a GPA of 2.00–2.49 and 2.50–2.99. The 2D group had the greatest number of students with a GPA above 3.00.

When considering the knowledge base experience, the responses showed that 72.2% of the students had no VR experience while video games playing experience had a range spanning between all experience levels with the majority having slight experience.

As for 2D plans reading experience, 66.7% of the students had no additional reading experience than what has been studied during their formal studies.

48.5% of the students had no construction site visits. The greatest number of visits was between 1–5 with a percentage of 42.4%.

TABLE III: SOCIO-DEMOGRAPHIC SURVEY RESPONSES

Variable		2D		3D		VR		Total	
	Total	11		12		10		33	
		#	%	#	%	#	%	#	%
Gender	Male	4	36.4	4.0	33.3	4.0	40.0	12.0	36.4
	Female	7	63.6	8.0	66.7	6.0	60.0	21.0	63.6
Age	16–18	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	19–21	7	63.6	7.0	58.3	5.0	50.0	19.0	57.6
	22–24	4	36.4	3.0	25.0	4.0	40.0	11.0	33.3
	25–27	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	>27	0	0.0	2.0	16.7	1.0	10.0	3.0	9.1
GPA	<2.00	1	9.1	0.0	0.0	0.0	0.0	1.0	3.0
	2.00–2.49	3	27.3	5.0	41.7	3.0	30.0	11.0	33.3
	2.50–2.99	3	27.3	4.0	33.3	6.0	60.0	13.0	39.4
	3.00–3.50	3	27.3	1.0	8.3	1.0	10.0	5.0	15.2
	>3.50	1	9.1	2.0	16.7	0.0	0.0	3.0	9.1
VR experience	No experience	10	90.9	8.0	66.7	6.0	60.0	24.0	72.7
	Slight experience	1	9.1	3.0	25.0	3.0	30.0	7.0	21.2
	Moderate experience	0	0.0	1.0	8.3	0.0	0.0	1.0	3.0
	Very experienced	0	0.0	0.0	0.0	1.0	10.0	1.0	3.0
Video Games experience	No experience	3	27.3	3.0	25.0	2.0	20.0	8.0	24.2
	Slight experience	4	36.4	5.0	41.7	6.0	60.0	15.0	45.5
	Moderate experience	2	18.2	2.0	16.7	1.0	10.0	5.0	15.2
	Very experienced	2	18.2	2.0	16.7	1.0	10.0	5.0	15.2
2D Plan Reading	No additional plans	6	54.5	8.0	66.7	8.0	80.0	22.0	66.7
	1–5 plans	4	36.4	4.0	33.3	0.0	0.0	8.0	24.2

experience	6–10 plans	1	9.1	0.0	0.0	1.0	10.0	2.0	6.1
	>10 plans	0	0.0	0.0	0.0	1.0	10.0	1.0	3.0
Construction site visits	No visits	7	63.6	6.0	50.0	3.0	30.0	16.0	48.5
	1–5 visits	3	27.3	5.0	41.7	6.0	60.0	14.0	42.4
	6–10 visits	0	0.0	1.0	8.3	0.0	0.0	1.0	3.0
	>10 visits	1	9.1	0.0	0.0	1.0	10.0	2.0	6.1

B. Performance Scores

Table IV below shows the average score (Avg) and standard deviation (SD) for students' performance per group.

Considering the scores of students, the average score of identified mistakes for 2D, 3D and VR groups were 2.5, 6.6 and 7.5 out of 12 total mistakes. This shows that the least performing group was 2D while the top performing group was VR followed by 3D. Time factor also indicates a shorter duration for the VR and 3D group in comparison to the 2D group which took the whole 15 minutes to complete the assessment, even though, they still scored the lowest. It is also worth mentioning that the GPA of the 2D group was higher than the 3D and VR group.

TABLE IV: PERFORMANCE SCORES

Group	2D		3D		VR	
Number of Students	N=11		N=12		N=10	
Results	Avg	SD	Avg	SD	Avg	SD
Average identified mistakes (out of 12)	2.5	1.7	6.6	2.5	7.5	2.5
Average wrongly identified mistake category	2.9	1.2	2.4	1.0	2.5	0.8
Average Time	15:00		11:17		9:20	

The average time for the VR group was 9:20 while the 3D group averaged at 11:17, a 1:57 time difference. This shows the level of comfort of the 3D and VR groups in comparison to the 2D group. In addition to the correctly identified mistakes, a very important aspect to consider was the average wrongly identified mistake category. The 2D group wrongly identified 3 different mistake categories in comparison to 3D and VR groups. This shows that using 2D plans can cause misinterpretations in plans resulting in wrong decisions, while in utilizing 3D and VR, more accurate decisions are made.

C. Intrinsic Motivation Inventory survey

For this survey, the average of the seven motivation questions was computed per student. For questions 3 and 4, the reverse score had to be considered since a higher score indicates increased motivation.

The following Table V shows the average motivation score for all students in the three groups.

TABLE V: INTRINISC MOTIVATION INVENTORY RESPONDS

Group	Case	Motivation Score (Avg)
2D	Avg	5.4
	SD	1.2
3D	Avg	6.6
	SD	0.5
VR	Avg	6.6
	SD	0.6

From the average values in Table V, it can be concluded that the 2D group was the least motivated towards the task when compared to 3D and VR groups who had a very close motivation score.

For further analysis, a Mann Whitney U-Test [12] was conducted to obtain the *U-value*, *z-score* and *p-value* to identify if the motivation of two groups of students was statistically different. A two-tail hypothesis and a significance level of 0.05 were chosen and results are shown in Table VI.

TABLE VI: MANN-WHITNEY U-TEST

Mann Whitney U-Test				
		U-Value	*z-score*	*p-value*
Group	2D & 3D	28.00	2.31	0.02
	2D & VR	21.50	−2.32	0.02
	3D & VR	52.50	−0.46	0.65

The *p*-value indicates a significant difference between the motivation levels of the 2D and 3D groups and the 2D and VR groups, while no significant difference was seen when comparing the 3D and VR groups. This shows that the motivation scores of the 3D and VR groups were very close in comparison to the 2D group. Students who completed the assessment using the 2D plans found it rather boring and less enjoyable than students that completed the assessment using the 3D and VR tools.

D. Performance and Motivation

To find if a relationship between performance and motivation exists, Spearman correlation was conducted between the motivation scores represented by the average score of each student per group and the performance scores represented by identified mistakes and wrongly identified mistake category for each student per group. Table VII shows the findings.

TABLE VII: SPEARMAN CORRELATION BETWEEN MOTIVATION AND PERFORMANCE

	Motivation		
	2D Group	3D Group	VR Group
Identified Mistakes	0.4	−0.2	0.6
Wrongly Identified Mistake Category	0.0	−0.1	0.4

A Spearman correlation coefficient of 0.6 reflects a strong correlation between the motivation score and identified mistakes score [13]. On the other hand, research [14, 15] indicates that 0.6 spearman correlation coefficient shows a moderate to strong correlation. It can be concluded that the correlation value shows a moderate/strong correlation between identified mistakes and motivation for the VR group. This means, the more students were motivated when using VR, the more they were able to correctly identify structural mistakes.

A coefficient of 0.4 between motivation and wrongly identified mistake category shows a moderate correlation.

VR gives the ability for a complete immersive experience and ease of navigation in a 360-degree view; whereas the 3D model requires pointing and rotating the screen to visualize the whole project.

The remaining correlation coefficients for the 2D group and 3D group reflects a moderate and no correlations therefore, are not further discussed here.

VI. Conclusion

Using BIM tools such as Autodesk Revit® and Enscape® to represent building designs in 3D and VR, undergraduate civil engineering students in their second year, were assessed on identifying structural mistakes on a concrete designed building using 2D plans, 3D models in real time rendering software and VR.

It was found that students who used 3D and VR had an average mistake identification score that is considerably higher than that for students using 2D plans. In addition, the time required by the 2D group was longer than VR and 3D group respectively. Despite taking longer time, they still scored the lowest. Spearman correlation coefficient of the VR group indicates that higher motivated students resulted in better performance when compared to the 2D and 3D groups. This research is exploratory, and replication of the experiment is anticipated to expand the findings.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Mohamad Iyad Al-Khiami conducted the design, implementation and experimental work of the research and wrote the paper. Martin Jaeger proposed the methodological approach and data analysis procedure. Sayed Mohamad Soleimani supervised the whole research and gave many constructive ideas. Martin Jaeger and Sayed Mohamad Soleimani revised, provided valuable input in the results and conclusion, and proof-read the final draft. All authors revised and approved the final version.

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References

[1] H. Faridi, N. Tuli, A. Mantri, G. Singh, and S. Gargrish, "A framework utilizing augmented reality to improve critical thinking ability and learning gain of the students in physics," *Computer Application in Engineering Education*, vol. 29, no. 1, pp. 258–273, 2021.

[2] M. Soliman, A. Pesyridis, D. Dalaymani-Zad, M. Gronfula, and M. Kourmpetis, "The Application of Virtual Reality in Engineering Education," *Applied Sciences*, vol. 11, no. 6, 2021.

[3] A. Zhang, C. J. Olelewe, C. T. Orji, N. E. Ibezim, N. H. Sunday, P. U. Obichukwu, and O. O. Okanazu, "Effects of innovative and traditional teaching methods on technical college students' achievement in computer craft practices," *SAGE Open*, vol. 10, no. 4, pp. 1–11, 2020.

[4] W. Huang and R. D. Roscoe, "Head-mounted display-based virtual reality systems in engineering education: A review of recent research," *Computer Applications in Engineering Education*, vol. 29, no. 5, pp. 1420–1435, 2021.

[5] S. Alizadehsalehi, A. Hadavi, and J. C. Huang, "Assessment of AEC students' performance using BIM-into-VR," *Applied Sciences*, vol. 11, no. 7, p. 3225, 2021.

[6] V. Dayarathna, S. Karam, R. M. Jaradat, M. Hamilton, M. Nagahi, S. Joshi, J. Ma, O. M. Ashour, and B. Driouche, "Assessment of the efficacy and effectiveness of virtual reality teaching module: A gender-based comparison," *International Journal of Engineering Education*, vol. 36, no. 6, pp. 1938–1955, 2020.

[7] F. M. Dinis, A. S. Guimaraes, B. R. Carvalho, and J. P. P. Martins, "Virtual and augmented reality game-based applications to civil engineering education," *IEEE Global Engineering Education*, pp. 1683–1688, 2017.

[8] S. Try, K. Panuwatwanich, G. Tanapornraweekit, and M. Kaewmoracharoen, "Virtual reality application to aid civil engineering laboratory course: A multicriteria comparative study," *Computer Applications in Engineering Education*, vol. 29, no. 6, pp. 1771-1792, 2021.

[9] J. A. Lanzo, A. Valentine, F. Sohel, A. Y. T. Yapp, K. C. Muparadzi, and M. Abdelmalek, "A review of the uses of virtual reality in engineering education," *Computer Applications in Engineering Education*, vol. 28, no. 3, pp. 748–763, 2020.

[10] G. K. Mweshi and K. Sakyi, "Application of sampling methods for the research design," *Archives of Business Research*, vol. 8, no. 11, pp. 180–193, 2020.

[11] R. M. Ryan and E. L. Deci, "Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being," *American Psychologist*, vol. 55, no. 1, pp. 68–78, 2000.

[12] H. Mann and D. Whitney, "On a test of whether one of two random variables is stochastically larger than the other," *The Annals of Mathematical Statistics*, vol. 18, no. 1, pp. 50–60, 1947.

[13] W. W. LaMorte, "PH717 module 9—correlation and regression," Boston University School of Public Health, 2021.

[14] H. Akoglu, "User's guide to correlation coefficients," *Turkish Journal of Emergency Medicine*, vol. 18, no. 3, pp. 91–93, 2018.

[15] P. Schober, C. Boer, and L. A. Schwarte, "Correlation coefficients: Appropriate use and interpretation," *Anasthesia & Analgesia*, vol. 126, no. 5, pp. 1764–1768, 2018.

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