

Understanding the Effectiveness of Using VR to Support Teaching Drilling Trajectory Concepts

Dr. Maryam Mirabolghasemi, Mississippi State University

Dr. Michael Andre Hamilton,

Dr. Michael A. Hamilton is an Associate Director at Mississippi State Institute for System Engineering Research (ISER) in Vicksburg, MS. He received his Doctorate, Master and Bachelor degrees in Industrial and Systems Engineering from Mississippi State University and has a graduate certificate in Modeling, Simulation, and Visualization Engineering from Old Dominion University. Currently, he is the technical lead for Big Data Analytic and Visualization, and Surrogate Modeling efforts in conjunction with the U.S. Army Engineer Research and Development Center (ERDC). Over the past 4 years, Dr. Hamilton have been leading the efforts for developing immersive virtual environments for conducting data analyzes of tradespace data sets. The immersive data visualization systems allows stakeholders the ability to visualize the tradespace options, subset the data, and work in collaboration with other analysts within the same virtual environment. Other research interest includes using virtual reality for enhancing classroom education in engineering programs.

Mr. Parker Jones, Mississippi State University

Parker Jones is a Research Engineer for the Institute for Systems Engineering Research at Mississippi State University and the U.S. Army Corps of Engineers. Parker received his BS in Industrial Engineering from Mississippi State University in 2012 and is currently pursuing a MSc in Industrial Engineering. He primarily develops software for virtual reality research projects and manufacturing simulations. Previously he worked as a Process Engineer at Shaw Industries in Dalton, GA.

Mr. David Cole, Mississippi State University

David Cole is an Instructor in Petroleum Engineering in the Swalm School of Chemical Engineering at Mississippi State University. He teaches a variety of courses including Drilling Engineering covering the topic of directional drilling. Prior to coming to Mississippi State, he had a 34 year career in engineering and leadership positions with Shell Oil Company. During that time, he spent time in drilling, completion, and producing operations, research and technology, and as discipline leader for Production Engineering for Shell's Western Hemisphere.

Mr. Cole has a B.S. in Mechanical Engineering from Mississippi State and an M.S. in Petroleum Engineering from Louisiana State University. He is a registered professional Petroleum Engineer (Louisiana) and a Life Member of the Society of Petroleum Engineers.

Mrs. Emily S. Wall , Mississippi State University

Emily Wall is a Research Engineer for the Center for Advanced Vehicular Systems Extension (CAVS-E). She graduated from Mississippi State University (MSU) with a masters of engineering (2018), bachelor's in Industrial and Systems Engineering in 2015, and received her Six Sigma Black Belt from MSU's CAVS Extension in June 2016. She is also working towards obtaining her PhD in Industrial Engineering and PE licensure through the MS State Engineering Board. Her current research involves lean six sigma practices and applications, manufacturability, modeling and simulations, and virtual reality applications. She also participates in the teaching of workshops and classes including: Introduction to Engineering, Gage RnR, Minitab, and Statistical Process Control.

Dr. Raed Jaradat, Mississippi State University

Dr. Raed Jaradat is an Assistant Professor of Industrial and Systems Engineering Department at Mississippi State University and a visiting research scientist working with the Institute for Systems Engineering Research/MSU/U.S. Army Corps of Engineers. Dr. Jaradat received a Ph.D. in Engineering Management and Systems Engineering from Old Dominion University in 2014. His main research interests include

systems engineering and management systems, systems thinking and complex system exploration, system of systems, virtual reality and complex systems, systems simulation, risk, reliability, and vulnerability in critical infrastructures with applications to diverse fields ranging from the military to industry. His publications appeared in several ranking journals including the IEEE Systems Journal, and the Computers & Industrial Engineering Journal. His total awarded projects exceed \$ 4.2 M including National Science Foundation (NSF), Department of Defense (DOD), Industry, and other Research Laboratories.

Understanding the Effectiveness of Using Virtual Reality to Support Teaching Drilling Trajectory Concepts

Abstract

As technology in the classroom gains popularity, the interest in virtual reality (VR) in education continues to grow. Benefits of using VR in the classroom include creating hands-on experiences for taught concepts and reaching more learning styles in students. This research aimed to create an educational VR environment teaching aid for petroleum engineering students to visually and spatially examine the results of calculated well trajectories. A study to examine the effectiveness of VR was performed on two student groups (VR Aided vs. Non-VR Aided). The research team's goal was to answer if wellbore trajectory quizzes and homework assignment scores would be higher for VR aided students, if VR aided students' overall cognitive workload would be lower than the non-VR aided students in regards to completing the wellbore assignment, and if the VR teaching aid would be considered positively in regards to enhancing understanding of calculating wellbore trajectory. Each group of students were taught the same lecture in a traditional classroom setting on the concepts of wellbore trajectory. Then the separated groups were given the same homework assignment and asked to manually solve for 3D well trajectory data. The non-VR group was asked to use Microsoft Excel to apply conversion formulas and determine the 3D well trajectories without a 3D visual aid. The VR group was asked to utilize the VR environment to visualize the 3D well trajectory path. Both groups compared their final results to the known solution. The paper will give an overview of the VR environment, how students interacted with the environment, and the results of the study.

Introduction

Virtual reality (VR) provides a realistic three-dimensional (3D) environment, which significantly reduces the cognitive workload associated with learning 3D geometrical concepts. VR not only allows students to interact with objects, but it also provides an interface to test complex geometrical concepts. An example of such complex concepts is the 3D (deviated) wellbore trajectory which allows for oil to be extracted from places unobtainable by conventional drilling. Design of deviated (non-vertical) wells requires a sound grasp of spatial relations and locations in 3D, along with adequate time to learn the concepts. Because of the time constraints in a semester, teaching efficiency needs improving to maximize student learning. In addition to theoretical calculations, students should be prepared to handle real life situations which necessitate quick and accurate decisions. To this end, the energy industry has adopted 3D visualization technologies and has acknowledged the change in learning styles of the new generation of engineers. Products such as Endeavor Drilling STS, RGU Oil and Gas Institute VR, and PaleBlue Drilling Simulators are all enabling users to drill in simulated environments and train employees [1], [2], [3].

VR provides a learning environment that can serve students with various learning styles. Research has shown that most engineering students are either convergers or assimilators in terms of their learning styles [4], [5]. Felder [6] explains that choosing a teaching style that matches the students' learning style, results in a significant improvement in students' learning experience. The traditional lecture-based teaching for topics such as drilling engineering only serves assimilator learners. Felder and Brent [5] argue that the incorporation of well-designed hypermedia teaching aids brings all types of learners to the same performance level. Simulation labs have been shown to improve students' ability to relate to the theoretical knowledge in the real world by providing a safe environment for students to learn by trial and error. Balamuralithara and Woods [7] emphasize the flexibility and accessibility of simulated labs. A subsurface simulated environment does not have a counterpart in the real world, so a simulated environment is the only opportunity for the students to have hands-on experience while learning about subsurface geology and drilling deep formations. It is now possible to establish simulated labs in 3D. These tools provide immersive training environments, where the user is part of the scene [8]. Studies have shown that the cognitive process that recognizes the relative positions of objects, is different in a 3D environment from that of a 2D non-immersive environment [9]. VR demonstrates better understanding of the spatial layout of the objects in the simulated environment compared to the 2D non-immersive environment [10]. The immersion has been proved particularly useful for training spatial tasks such as navigation [11], which is an essential skill required for a successful directional drilling operation.

One study [10] that investigated the efficacy of the immersive experience in oil well drilling developed the "Immersive Drilling Planner" software which visualizes the wellbores and formations in a mature oil field. This software allowed users to obtain a full grasp of the relative positions of the existing wellbores with respect to each other and to the formation. The users were asked to modify the path of a new well within VR so that it reached a certain target, while avoiding the other existing wellbores, and a second group was asked to complete the same task on a desktop. The comparison between the performances of the two groups showed that the VR users completed the task faster and with more correct answers than the desktop users. Although this study did not directly assess the pedagogical efficiency of the immersive experience, it supports the notion that VR is potentially useful in saving drilling class time by helping the students resolve spatially complicated problems quicker. Another study [12] explored well placement through VR where the users created vertical and free-form well paths in the immersive environment. The application analyzed the connectivity of the new wellbore to the reservoir and estimated the amount of recovery associated to the new well. The results were displayed in the 3D environment as well as in a table summarizing the calculated values. The study reported that the users expressed a positive experience with the visualization of the connectivity and recovery analysis. All the participants of this study were professionals and possessed prior knowledge of reservoir models and well placement, thus this study does not give much information on the pedagogical advantages of the immersive environment in the area of

well placement. The VR environment described in the work by Brasil [14] simulates a drilling rig and exposes the users to various circumstances to test their knowledge. Artificial intelligence is also applied to simulate emergency events and to allow for user interactions. There are few studies in the literature that specifically look at the learning effects of VR vs. traditional classroom methods. However, the results of the available studies all point to the positive effects of VR. An example of such research is a study of the effects of using the Google Cardboard smartphone VR application in the classroom which measured the feasibility of VR to improve the learning process [13]. Much like these results show, the response was positive and improved the understanding for students.

This study aims at developing a VR tool that enables the students to spatially examine the results of a familiar mathematical method taught to them in a traditional classroom setting. Specifically, this study focuses on developing a teaching aid to help the petroleum engineering students better understand the concept of deviated well trajectories in 3D. Our findings show that, not only do the students find the VR tool more helpful than 2D interfaces, but also, the VR tool has a measurable positive impact on students' perception of relative position of objects in 3D.

Research Objective

The primary objective was to examine the effectiveness of VR as an aid for teaching drilling trajectory related concepts. The VR environment allows the students to visually explore 3D wellbore trajectories and nearby faults, and interactively change certain parameters such as inclination angle and kick-off depth to see their effects on the overall wellbore trajectory. Specifically, this study quantifies the learning effectiveness by evaluating the quizzes and homework assignments of two groups (VR Aided vs. Non-VR Aided) of students.

Traditional Assignment & Virtual Teaching Aid Protocol

In the fall of 2018, 16 petroleum-engineering students enrolled in the drilling engineering course at Mississippi State University. This course covers the terminology and main parameters of 2D well trajectory design, and 3D well trajectory conversions between coordinate systems. Traditionally, the homework assignments assess the capability of designing 2D well trajectories as well as conversion formulas to determine the 3D well trajectories without a 3D visual aid. The wellbore trajectory virtual teaching aid was developed to provide students the ability to upload converted well trajectory data from Microsoft Excel to visualize the 3D well trajectory path and to compare their results with the known solution. The 3D visualization also includes other geological features such as faults, which are used to evaluate students' ability to understand spatial relationship between subsurface objects. In addition, the developed application provides an interactive interface where students are allowed to change trajectory design parameters, such as build rate, and visualize the resulting well path instantly.

Assignment Protocol

The fundamentals of developing wellbore drill trajectories are a current topic within the drilling engineering course. In order to minimize the impact on classroom interference, the research was conducted as a workshop in conjunction with the course schedule for teaching the drill trajectory concepts. The assignment was broken into five phases which are described below.

Part 1: Trajectory Calculations using Microsoft Excel

The students were given homework assignment for the class course material which required them to convert a given well trajectory from a system of measured depths, inclination angles, and azimuths into a system of true vertical depth (TVD) and compass directions (Fig. 1). The students had one week to complete the assignment. This was the only graded assignment during the research study that affected their course grade. Some phases of the research study required students to be placed into two groups (VR Aided and Control). Since there could be advantages gained by using the virtual aid, undue influences on the student grades were avoided to ensure a fair assessment of the students' understanding of the topic based on the current syllabus requirements.

The figure shows a conversion of well survey data. On the left, a blue table lists Measured Depth, Inclination Angle, and Survey Azimuth. A large grey arrow points to the right, where a pink table lists True Vertical Depth, North - South, and East - West. The data values are as follows:

Measured Depth	Inclination Angle	Survey Azimuth	True Vertical Depth	North - South	East - West
0	0	0	0.00	0.00	0.00
100	1.2	348.1	99.99	1.02	-0.22
200	1.12	1.8	199.97	3.03	-0.40
300	0.56	28	299.96	4.43	-0.14
400	0.52	26.1	399.95	5.27	0.29

Figure 1: Part 1 - Students were asked to convert a given well survey from a system of measured depth, inclination angle, and azimuth (left) to a system of true vertical depth and compass directions (right). The presented values are in feet.

Part 2: Homework Evaluation using VR and Excel

The workshop was conducted one week from the date the assignment was given to the students. The students brought their computers to the workshop and were separated into two groups for this phase of the experiment where the assignments were returned for review. The objective of this phase was to evaluate the perceived effectiveness of students using Excel versus VR to visualize the drill trajectory from the homework assignment. One group used the virtual aid and the other group used Excel to visualize their converted trajectories. Both groups were also given the visualized correct solution so they were able to compare their trajectories with the correct trajectory in the same environment. 2D Excel plots include graphs of the well paths on an east/west versus TVD and a north/south versus TVD plot.

Part 3: Evaluation of Wellbore Intersection with Faults

During this phase, faults are introduced to the assignment. A printout with a green fault, a red fault, and a wellbore trajectory on 2D plots was provided to the students (Fig. 2). The students were then asked if the trajectory crossed the green fault, red fault, both, or neither. Afterwards, the students used the virtual aid to determine if the well path intersected with the faults. Students were not split into groups for this phase.

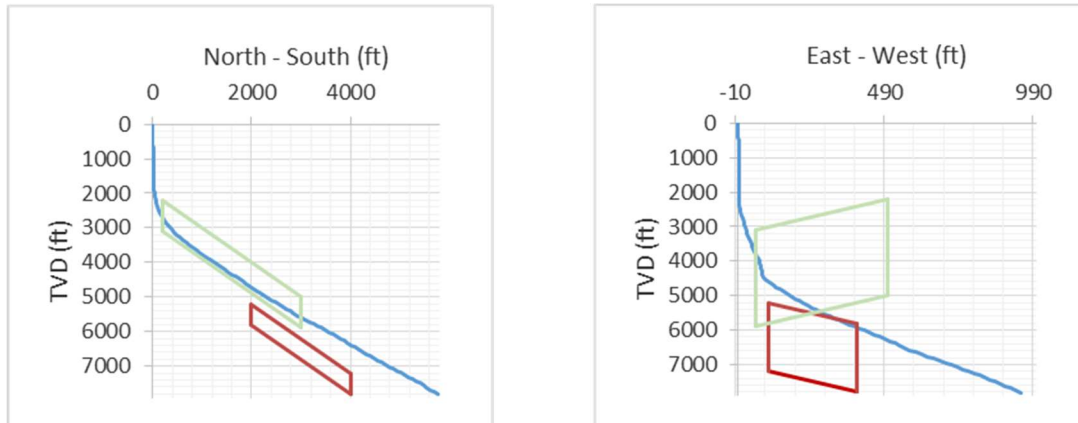


Figure 2: Part 3 – 2D plots of two faults and a well trajectory were given to the students and they were asked to determine if the wellbore intersects with any of the faults.

Part 4: Introduction of Tool Error

A depth measurement error of 10 ft /1000 ft was introduced to the assignment. Specifically, the tool error caused a 10 foot deviation from the correct path every 1000 feet below ground. All participants were provided an Excel spreadsheet with 2D plots of the new trajectory corrected for the tool error and the drill target location. The students were tasked to determine the effect of the tool error on the location of the endpoint of the wellbore path. They were asked about the cardinal direction of the updated wellbore's end point in relation to the expected target point, and were provided a worksheet to record their answers. After the solutions were collected, the students used the virtual aid to answer the same questions in which the solution were collected afterward as well.

Part 5: Build-And-Hold Trajectory Design

For this phase of the study, the participants in the control group and VR-aided groups were reversed. Both groups were provided information about a current drill design that would likely hit faults underground. The students in the control group were provided with a spreadsheet containing well trajectory calculations based on two design parameters: kick-off depths in feet and build rates in degrees per 100 feet. The spreadsheet allowed the students to change the design parameters and to visualize the resulting well trajectory instantly. The students were asked to determine the range of design parameters that would be feasible to avoid the faults. The VR-aided group was also provided with a similar interface in the virtual aid. The solutions were collected from both groups.

Virtual Teaching Aid Protocol

The virtual teaching aid was developed using the Unity3D game development platform. The Oculus VR headset and the Oculus touch controllers were used to provide the VR experience for the students. When the simulation was initiated, the system provided visual aids to assist the students in understanding the control mechanisms of the environment. The students were able to move in the physical world to translate the positions in the virtual environment. Below, Figure 3 shows the virtual wellbore and interface menu used for the classroom assignments.



Figure 3: Virtual wellbore world & interface menu

The student's virtual perspective to the wellbore was third person omniscient. They were able to physically walk around the virtual wellbore world, translate, rotate, and scale the virtual wellbore world, and view the underground trajectory path of their well. A compass was provided on top and underneath the ground level.

Phase 1: Trajectory Calculations using Microsoft Excel

The students converted their Excel spreadsheets to Comma Separated Variables (CSV) files and stored them in the resource file directory of the simulation. The homework included five questions and the students would select the question they wanted to evaluate their results with the virtual training aid under the "Select Question" option. Once selected, the students would select their file from the resource directory and click the "Load File" button. Different capabilities were provided to the students based on which question they selected. In general, the students were able to toggle their well path vector points on/off, toggle fault lines on/off, and manipulate the build rate and kickoff depth of the provided well path for question five only. The interactive data table allowed the students to verify whether they uploaded the correct dataset to the simulation. Afterwards, 2D cross sections of the well path were provided of the drill trajectory depth and cardinal directions.

Phase 2: Homework Evaluation with VR Teaching Aid Protocol

Once the student file was uploaded, their drill trajectory path was drawn in the virtual world in the simulation. The simulation provided a target point indicating the correct drill path end point. The students were able to press the “Analyze Results” button on the interface and the simulation changed the color of their well path to either green or red. A green colored path represented a correct solution and a red colored path represented an incorrect solution. The students were not provided access to the data file for the correct path, but were able to adjust their paths in Excel and resubmit their new solutions to analyze the correctness of their well paths. Figure 4 shows a student drill path which was analyzed as an incorrect solution for this phase of the assignment.

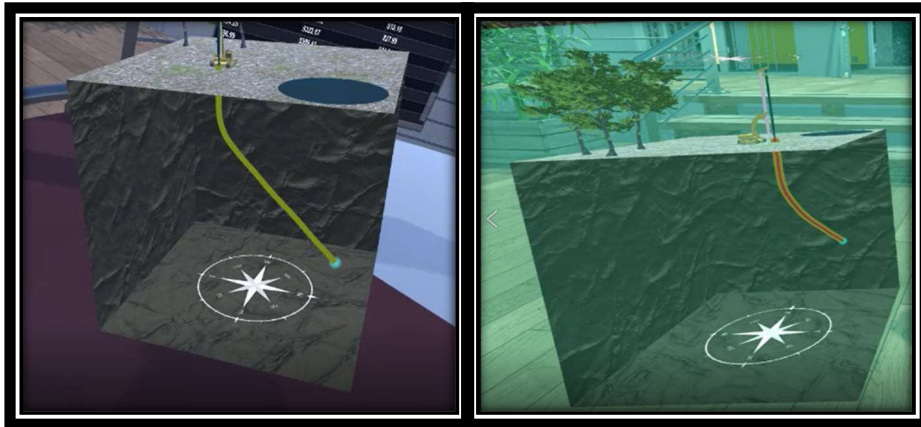


Figure 4: Simulated drill path

Phase 3: Intersection with Fault Evaluation

At this phase, the students had been given the correct drill path for phase two and 3D visualization of the fault's intersection. A fault was displayed using a green or red plane added to the scene. When investigating the intersection with the virtual aid, they could transform, rotate, and scale the virtual world for closer inspections and also manipulate their physical positions in the real world for further investigation.

Phase 4: Introduction of Tool Error

After the introduction of the tool error, the students investigated the deviation from the original drill target. The virtual aid displayed the drill path with the tool error and the deviation from the target.

Phase 5: Build-And-Hold Trajectory Design

During this phase of the experiment, the students could manipulate the kick-off depths and build rates and receive real-time visual updates of the effects those parameters have on the drill trajectory path. Figure 5 (right) shows an example of manipulation of parameters and the effects of the drill path trajectory. The students had to identify the solution space of correct kick-

off depths and build rates in which the drill path would not intersect the fault. Figure 5 (left) shows an example of an infeasible solution with a build rate of $2^0 / 100$ feet, kickoff depth of 1600 feet, and a feasible solution with the same build rate but larger kickoff depth (right).

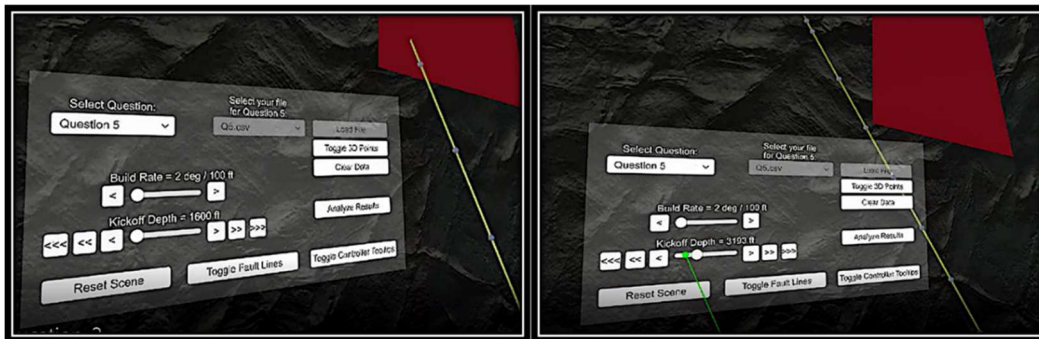


Figure 5: Build rate & kick-off depth

Experimental Methodology

This experiment was conducted in a control laboratory classroom environment in which three VR module setups were provided which allowed three students to use the virtual training aid at a given time. Ten of the sixteen students enrolled in the course participated in the research study. During the semester of this study, no females enrolled in the class. There were two students of African descent and the other eight students were of Caucasian descent. The average age of the students were 24 years old with a standard deviation of 1.35 years. The average GPA of the students was 3.05 with a standard deviation of .54 points. The two independent variables measured in this study was Group Type with two levels (VR Aided – Non-VR Aided) and GPA Group with two levels (Below 3.0 – Above 3.0).

The dependent variables were collected using surveys that provided either questions to evaluate their perceived usefulness of using the technologies, multiple choice questions, or fill-in-the-blank questions for collecting results of numerical feasible solutions. The perceived usefulness questions were collected using a Likert scale with a range from zero to nine. Most of the perceived usefulness questions were focused on the helpfulness of the technologies in assisting with answering the drill trajectory questions. The results for the questions determined which of the five-usefulness levels perceived by the students of the technology types. The usefulness levels were listed as follows: Not Much (1-2), Somewhat (3-4), Helpful (5-6), Very Helpful (7-8), Very Much (9). Statistical software R (version 3.3.1) was used to conduct the data analysis for the study with the integrated development environment RStudio. R is a statistical computer environment and language that was developed by Bell Laboratories. It provides a large variety of statistical and graphical capabilities and is an open source product [14].

Results and Data Analysis

The next subsections are subdivided based on the research part described in the previous sections. Due to the small sample size and non-normality of the data set, the Kruskal-Wallis test, a non-parametric method, was used to analyze the statistical difference between independent

variables evaluated in this research effort. If significance was found between treatments, the Kruskal-Wallis multiple comparison Test (R package “kruskalmc”) was used to evaluate the severity of significance between the treatments from the critical difference value.

Part 2 Results

After the completion of the phase, the students were given a survey that asked the following two questions: (Q1) “How helpful was the technology in visualizing the well path?” (Q2) “How helpful was the technology in your understanding of the drill path trajectory?” The results from the Kruskal-Wallis and Multiple Comparisons (MC) test results are shown below in Table 1 and Table 2.

Table 1: Part 2: Kruskal-Wallis results

How helpful visualizing the well path...			
Source	Chi-Squared	DF	P-Value
Group Type	4.64	1	.031
GPA Group	.334	1	.562
How helpful was the technology...			
Source	Chi-Squared	DF	P-Value
Group Type	6.05	1	.013
GPA Group	1.30	1	.2538

Table 2: Part 2: Kruskal-Wallis MC results

How helpful visualizing the well path...			
Source	Observed Diff.	Critical Diff.	Significant Diff.
Non-VR Aided ~ VR Aid	3.8	.375	True
How helpful was the technology...			
Source	Observed Diff.	Critical Diff.	Significant Diff.
Non-VR Aided ~ VR Aid	4.4	3.75	True

The Kruskal-Wallis test showed there was a significant difference between the perceived usefulness of using Excel versus the virtual teaching aid for both survey questions. The MC post-hoc test shows the severity of the observed differences between the technology types and the critical difference value of significance. If the observed difference is greater than the critical difference, the difference between treatments will be significant. The box plot in Figure 6 below graphically shows the difference between the results.

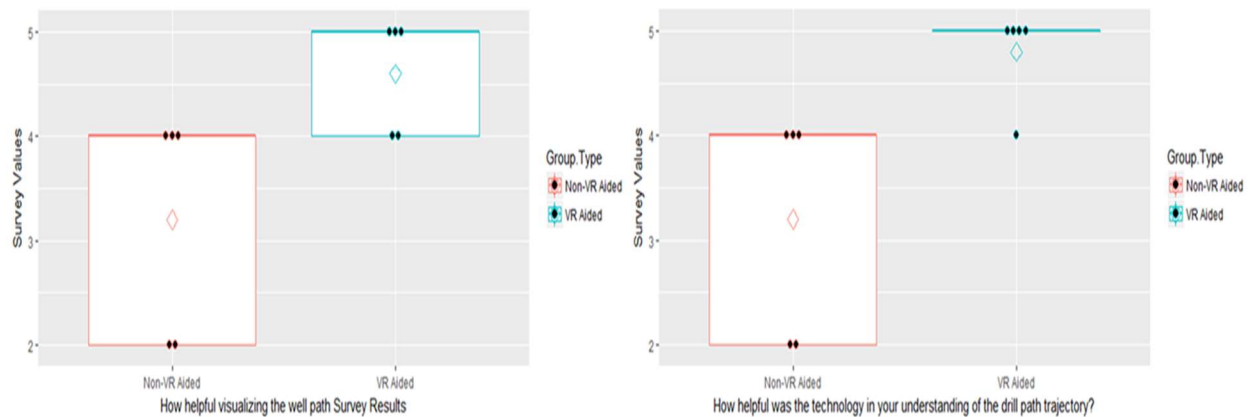


Figure 6: Part 2 Q1 & Q2 group type box plot

The y-axis of the box plot represents the usefulness levels: Not Much (1), Somewhat (2), Helpful (3), Very Helpful (4), Very Much (5). The diamond represents the mean of the dataset. The plot shows that the students using the virtual teaching aid had an average mean value of 4.6

and 4.8 respectively, and the students using Excel had an average mean of 3.2 and 3.2 respectively in regards to the perceived usefulness of the technology type.

Part 3 Results

First, the students were given a survey that asked the following two questions: (Q1) “Which fault(s) intersect(s) with the wellbore?” (Q2) “Was identifying if the drill trajectory intersects the faults easy?” Question 1 was a multiple-choice question with the following options: (A) Green Fault (B) Red Fault (C) Neither (D) Both. The correct answer for this question was A. The plot in Figure 7 shows the results for both Q1 and Q2.

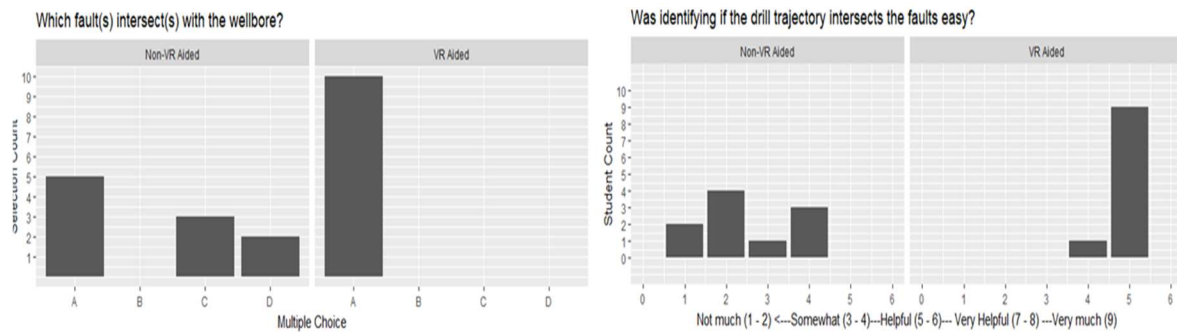


Figure 7: Part 3: Q1 & Q2 survey results

The results show that 50% of the students answered the question correctly using Excel and 100% of the students answered correctly using the virtual teaching aid. The students’ perceived level of ease in identifying the fault using the virtual teaching aid was an average mean of 4.9, and using Excel their average mean was 2.5. The results from the Kruskal-Wallis and Multiple Comparisons (MC) test results are shown below in Table 3 and Table 4.

Table 3: Part 3 Kruskal-Wallis results

Which faults intersects with the wellbore...			
Source	Chi-Squared	DF	P-Value
Group Type	6.33	1	.011
GPA Group	0	1	1
Was identifying if the drill trajectory intersects...			
Source	Chi-Squared	DF	P-Value
Group Type	15.25	1	<.0001
GPA Group	.041	1	.8388

Table 4: Part 3 Kruskal-Wallis MC results

Which faults intersects with the wellbore...			
Source	Observed Diff.	Critical Diff.	Significant Diff.
Non-VR Aided ~ VR Aid	5	5.185	False
Was identifying if the drill trajectory intersects...			
Source	Observed Diff.	Critical Diff.	Significant Diff.
Non-VR Aided ~ VR Aid	9.8	5.185	TRUE

For Q1, significance difference testing was based on fault selection correctness. The Kruskal-Wallis test showed there was a significant difference in the fault selection correctness based on the technology type. However, the MC failed to show significance between the treatments. In regards to the perceived ease of identifying the intersecting fault, the Kruskal-Wallis and MC test showed a significant difference between the technology types used to solve the problem.

Part 4 Results

During this phase, the students were given a survey that asked the following questions: (Q1) “What is the location of the target with respect to the end point of the corrected survey?” (Q2) “Was the Excel aid useful in identifying how the tool error caused deviation from the target?” (Q3) “Was the VR aid useful in identifying how the tool error caused deviation from the target?” (Q4) “Was the VR aid more helpful than Excel in identifying the location of the target with respect to the endpoint?” Q1 was a multiple-choice question for which the students had to identify the new location of the wellbore trajectory’s end point. The students selected three options based on the cardinal direction of the corrected survey’s end point with respect to the target. The options were (North or South), (East or West), and (Deeper or Shallower). The correct answer was the new endpoint located northeast and deeper with respect to the target location. The Kruskal-Wallis test results are shown below on Table 5.

Table 5A: Part 4 Kruskal-Wallis results

North VS South			
Source	Chi-Squared	DF	P-Value
Group Type	.253	1	.6147
GPA Group	1.0556	1	.3042
East VS West			
Source	Chi-Squared	DF	P-Value
Group Type	.372	1	.5416
GPA Group	.993	1	.3189

Table 5B: Part 4 Kruskal-Wallis results

Deeper VS Shallower			
Group Type	.253	1	.6147
GPA Group	0	1	1
Was the Excel/VR useful in identifying tool error...			
Group Type	13.997	1	<.001
GPA Group	.128	1	.7204

The Kruskal-Wallis test showed that there was not a significant difference between treatment groups for this phase of the study. In addition, a significant difference was not found between Q2 and Q3 as well with average perceived levels of usefulness scores of 4.7 and 4.6. However, a significant difference was found in the perceived usefulness of identifying the deviation from the target between technology types. The MC test is shown in Table 6 for Q4 below.

Table 6: Q4 Kruskal-Wallis MC results

Was the Excel/VR useful in identifying tool error...			
Source	Observed Diff.	Critical Diff.	Significant Diff.
Non-VR Aided ~ VR Aid	9.6	5.185	True

The MC post-hoc test results showed a large observed difference - critical difference comparison between technology types in regards to perceived usefulness. The virtual teaching aid and Excel perceived usefulness average mean scores were 4.6 and 2.2 respectively.

Part 5 Results

During this phase of the study—after the students were placed back into group—they were asked to provide kickoff angles and build rates that would not cause the trajectory to

intersect with the fault. The students were able to provide up to five feasible solutions. The Kruskal-Wallis and MC test results are shown in Table 7 and Table 8 below.

Table 7: Part 5 Kruskal-Wallis results

Build Rate			
Source	Chi-Squared	DF	P-Value
Group Type	4.622	1	.031
GPA Group	2.138	1	.143
Kickoff Depth			
Source	Chi-Squared	DF	P-Value
Group Type	6.67	1	.009
GPA Group	5.801	1	.016

Table 8: Part 5 Kruskal-Wallis MC results

GPA Group ~ Kickoff Depth			
Source	Observed Diff.	Critical Diff.	Significant Diff.
Above 3.0 ~ Below 3.0	10.11	8.29	True
Group Type ~ Build Rate			
Source	Observed Diff.	Critical Diff.	Significant Diff.
Non-VR Aided ~ VR Aid	8.98	8.29	True
Group Type ~ Kickoff Depth			
Source	Observed Diff.	Critical Diff.	Significant Diff.
Non-VR Aided ~ VR Aid	10.92	8.29	True

The Kruskal-Wallis test showed a significant difference between technology types for build rate and a significant difference for both treatment groups in regards to the kick off depth. The box plot shown in Figure 8 below shows that the kick-off depths reported by the students with an above 3.0 GPA average was 339 feet higher than students with GPAs below 3.0. Students using the virtual teaching aid kickoff depth was on average 392 feet higher than the Excel group and the build rate was 1.52 degrees per feet higher than the Excel group.

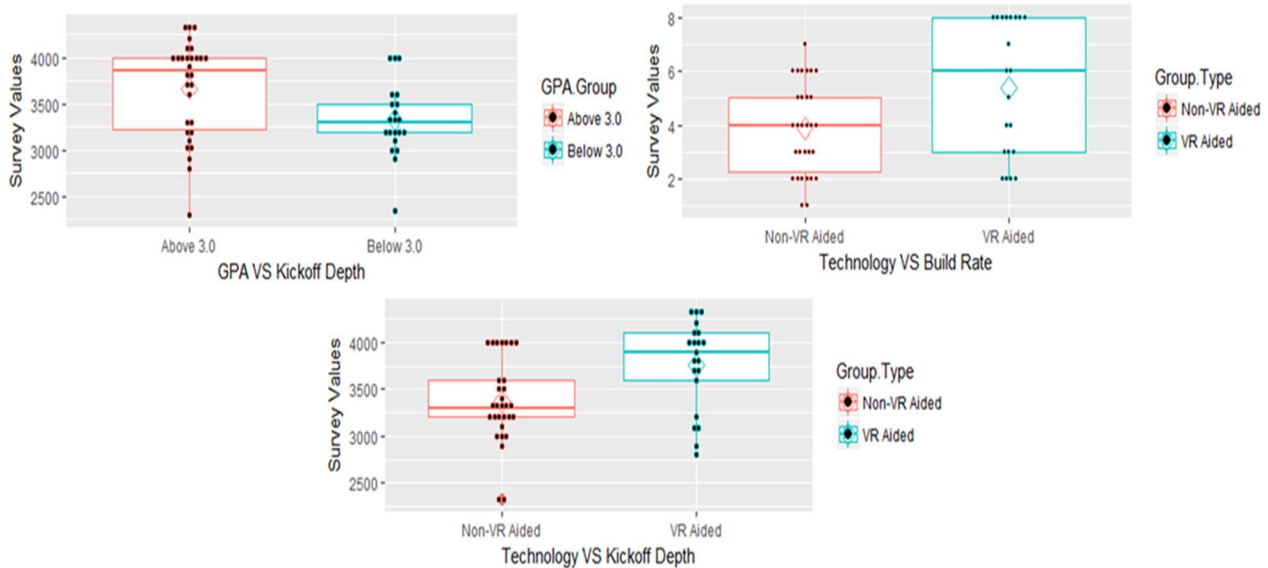


Figure 8: Part 5 significant treatment box plot

Discussion and Conclusion

In regards to the perceived usefulness of the VR teaching aid compared to using Excel, the students concluded that using the virtual aid was significantly more helpful for understanding the wellbore drill trajectory concepts. For phase five, the results showed significance between technology type for both build rate and kickoff depth. However, this significance could be

skewed by the VR aid's user interface design. Students using VR were limited in the range of available kickoff depths and build rates. When using Excel, students could input any range of numbers for both kickoff depth and build rate. In the future, VR aided students could be provided a virtual keyboard to input numbers. Also, students will be required to identify the optimal path with minimum well length instead of only identifying feasible well paths. By providing an optimal goal, the hypothesis that the VR aid would provide more optimal results would likely prove successful.

In the area of fault intersection detection, VR offered a clear advantage over Excel due to the ability to visualize the trajectory in 3D. The students found it difficult to identify the intersecting faults using 2D plots. Also, the VR environment facilitated the recognition of spatial relationships between the objects (wellbore and faults). This finding is both expected and significant. However, the 3D visualization did not seem to significantly affect the decision making of the students in regards to the displacement of the trajectory due to tool error and the results showed that there was not a significant difference between the groups. The team speculates that this lack of difference is because of the relatively small deviation from the target point, which made it difficult to confidently discern the actual deviation from target using the cardinal directions in both VR and Excel. In the future design changes to the virtual interface will be implemented to aid students to identify small changes easier. Even though the outcomes were roughly equal between the technology types, the students unanimously thought that the VR aid aided concept understanding more than Excel.

Acknowledgement

This project has been partially supported by a grant from Mississippi State University's Otilie Schillig Special Teaching Projects and Dave C. Swalm School of Chemical Engineering.

References

- [1] “Endeavor Drilling Safety Training Simulators.” (8 January, 2019). Retrieved from <http://drillingsimulator.com/#about>.
- [2] “RGU Oil and Gas Institute.” (8 January, 2019). Retrieved from <http://www.rguoilandgasinstitute.com/simulator-facilities/virtual-reality/>.
- [3] “PaleBlue Drilling Technology.” (8 January, 2019). Retrieved from <https://pale.blue/simulators/drilling/>.
- [4] C. E. Baukal and L. J. Ausburn, “Learning strategy and verbal-visual preferences for mechanical engineering students,” *Am. Soc. Eng. Educ.*, vol. 121, 2014.
- [5] RICHARD M. FELDER and REBECCA BRENT, “Understanding Student Differences,” *J. Eng. Educ.*, no. January, pp. 57–72, 2005.
- [6] R. M. Felder, “Are Learning Styles Invalid? (Hint: No!),” *On-Course Newsletter*, Sept. 27, 2010, no. January, pp. 57–72, 2010.
- [7] B. Balamuralithara and P. C. Woods, “Virtual laboratories in engineering education: the simulation lab and remote lab,” *Comput. Appl. Eng. Educ.*, vol. 17, no. 1, pp. 108–118, 2009.
- [8] M. Kozhevnikov and J. Gurlitt, “Immersive and non-immersive virtual reality system to learn relative motion concepts,” *Proc. 3rd Interdiscip. Eng. Des. Educ. Conf. IEDEC 2013*, pp. 168–172, 2013.
- [9] M. Kozhevnikov, J. Royan, and O. Blazhenkova, “The Role of Immersivity in Three Dimensional Mental Rotation,” *Des. Comput. Cogn.*, no. January, pp. 143–157, 2008.
- [10] K. Gruchalla, “Immersive well-path editing: Investigating the added value of immersion,” *Proc. - Virtual Real. Annu. Int. Symp.*, pp. 157–164, 2004.
- [11] M. Kozhevnikov and A. Garcia, “Visual-Spatial Learning and Training in Collaborative Design in Virtual Environments,” in *Collaborative Design in Virtual Environments, Intelligent Systems, Control and Automation: Science and Engineering*, Springer, Dordrecht, 2011, pp. 17–26.
- [12] R. C. Ramos Mota, S. Cartwright, E. Sharlin, H. Hamdi, M. Costa Sousa, and Z. Chen, “Exploring Immersive Interfaces for Well Placement Optimization in Reservoir Models,” *Proc. 2016 Symp. Spat. User Interact. - SUI '16*, pp. 121–130, 2016.
- [13] A. B. Ray and S. Deb, “Smartphone Based Virtual Reality Systems in Classroom Teaching - A Study on the Effects of Learning Outcome,” *Proc. - IEEE 8th Int. Conf. Technol. Educ. T4E 2016*, no. 978, pp. 68–71, 2017.
- [14] “What is R?” (8 January, 2019). Retrieved from <https://www.r-project.org/about.html>.