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Development of Virtual Environment to Introduce Spatial Reasoning to First- and Second-year Engineering Students

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Dr. Reg Pecen is currently a Quanta Endowed Professor of the Department of Engineering Technology at Sam Houston State University in Huntsville, Texas. Dr. Pecen was formerly a professor and program chairs of Electrical Engineering Technology and Graduate (MS and Doctoral) Programs in the Department of Technology at the University of Northern Iowa (UNI). Dr. Pecen served as 2nd President and Professor at North American University in Houston, TX from July 2012 through December 2016. He also served as a Chair of Energy Conservation and Conversion Division at American Society of Engineering Education (ASEE). Dr. Pecen holds a B.S in EE and an M.S. in Controls and Computer Engineering from the Istanbul Technical University, an M.S. in EE from the University of Colorado at Boulder, and a Ph.D. in Electrical Engineering from the University of Wyoming (UW, 1997). He served as a graduate assistant and faculty at UW, and South Dakota State University. He served on UNI Energy and Environment Council, College Diversity Committee, University Diversity Advisory Board, and Graduate College Diversity Task Force Committees. His research interests, grants, and more than 50 publications are in the areas of AC/DC Power System Interactions, distributed energy systems, power quality, and grid-connected renewable energy applications including solar and wind power systems. He is a senior member of IEEE, member of ASEE, Tau Beta Pi National Engineering Honor Society, and ATMAE. Dr. Pecen was recognized as an Honored Teacher/Researcher in "Who's Who among America's Teachers" in 2004-2009. Dr. Pecen is a recipient of 2010 Diversity Matters Award at the University of Northern Iowa for his efforts on promoting diversity and international education at UNI. He is also a recipient of 2011 UNI C.A.R.E Sustainability Award for the recognition of applied research and development of renewable energy applications at UNI and Iowa in general. Dr. Pecen established solar electric boat R & D center at UNI where dozens of students were given opportunities to design solar powered boats. UNI solar electric boat team with Dr. Pecen's supervision won two times a third place overall in World Championship on solar electric boating, an international competition promoting clean transportation technologies in US waters. He was recognized as an Advisor of the Year Award nominee among 8 other UNI faculty members in 2010-2011 academic year Leadership Award Ceremony. Dr. Pecen received a Milestone Award for outstanding mentoring of graduate students at UNI, and recognition from UNI Graduate College for acknowledging the milestone that has been achieved in successfully chairing ten or more graduate student culminating projects, theses, or dissertations, in 2011 and 2005.

He was also nominated for 2004 UNI Book and Supply Outstanding Teaching Award, March 2004, and nominated for 2006, and 2007 Russ Nielson Service Awards, UNI. Dr. Pecen is an Engineering Technology Editor of American Journal of Undergraduate Research (AJUR). He has been serving as a reviewer on the IEEE Transactions on Electronics Packaging Manufacturing since 2001. Dr. Pecen has served on ASEE Engineering Technology Division (ETD) in Annual ASEE Conferences as a reviewer, session moderator, and co-moderator since 2002. He served as a Chair-Elect on ASEE ECC Division in 2011. He also served as a program chair on ASEE ECCD in 2010. He is also serving on advisory boards of International Sustainable World Project Olympiad (isweep.org) and International Hydrogen Energy Congress. Dr. Pecen received a certificate of appreciation from IEEE Power Electronics Society in recognition of valuable contributions to the Solar Splash as 2011 and 2012 Event Coordinator. Dr. Pecen was formerly a board member of Iowa Alliance for Wind Innovation and Novel Development (www.iawind.org/board.php) and also represented UNI at Iowa Wind Energy Association (IWEA). Dr. Pecen taught Building Operator Certificate (BOC) classes for the Midwest Energy Efficiency Alliance

(MEEA) since 2007 at Iowa, Kansas, Michigan, Illinois, Minnesota, and Missouri as well as the SPEER in Texas and Oklahoma to promote energy efficiency in industrial and commercial environments.

Dr. Pecen was recognized by State of Iowa Senate on June 22, 2012 for his excellent service and contribution to state of Iowa for development of clean and renewable energy and promoting diversity and international education since 1998.

Dr. Faruk Yildiz, Sam Houston State University

Faruk Yildiz is currently an Associate Professor of Engineering Technology at Sam Houston State University. His primary teaching areas are in Electronics, Computer Aided Design (CAD), and Alternative Energy Systems. Research interests include: low power energy harvesting systems, renewable energy technologies and education.

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EXPERIENCE Aug. 2016 – Present: Assistant Professor, Mechanical and Industrial Engineering, Texas A & M University-Kingsville, TX, USA Dec. 2012 – April 2016: Senior Structural Engineer, Aker Solutions, Houston, USA Feb. 2007 – Dec.2012: Senior Structural Engineer, American Bureau of Shipping (ABS), Houston, USA Jan. 2006 – Feb.2007: Research Associate, Mech. Engr., Louisiana State University, USA Aug. 2002 –Dec.2005: Instructor & Research Assistant, Mechanical Engr., Louisiana State University, USA Oct. 1997 – Aug.2000: Assistant Professor, Bangladesh University of Engineering and Technology, Bangladesh Nov. 1994 – Oct.1997: Naval Architect, Chittagong Dry Dock Ltd, Bangladesh.

REGISTRATION Registered Professional Engineer in Texas (TBPE No. 113655) SELECTED HONORS AND AWARDS (1) Louisiana State Economic Development Award (2002-2004), Louisiana State University (LSU). (2) Teaching and Research Fellowship/Assistantships: South Dakota School of Mines & Tech and LSU. (3) Dissertation Fellowship Award (2005), LSU. (4) Nominee for Best Research Assistant Award (2004), LSU. (5) Nominee for Distinguished Dissertation Award (2005), LSU

PUBLICATIONS (Dr. Alam has published over 20 refereed journal papers/conference proceedings.)

List of Selected Peer-Reviewed Publications:

1. M.S. Alam, M.A. Wahab and C.H. Jenkins, "Mechanics in Naturally Compliant Structures," Journal of Mechanics of Material, 39, pp.145-160, 2007. 2. M.A. Wahab, M.S. Alam, Su-Seng Pang and Jerry Pack, "Stress analysis of non-conventional composite pipes" Journal of Composite Structures, 79(1), 2006, pp. 125-132. 3. M.A. Wahab, M. S. Alam, M.J Painter and P.E. Stafford, "Experimental and Numerical Simulation of Restraining Forces in Gas Metal Arc Welded Joint," American Welding Journal (Research Supplement) 85(2), February, 2006. 4. M.S. Alam and M.A. Wahab, "Modeling of Fatigue Crack Growth and Propagation Life of Joint of Two Elastic Materials Using Interface Elements," International Journal of Pressure Vessel and Piping, 82, 2005, pp. 105-113. 5. M.S. Alam and C.H. Jenkins, "Damage Tolerance Design in Naturally Compliant Structures," International Journal of Damage Mechanics, 14(4), 2005, pp. 365-384. 6. M.S. Alam and M.A. Wahab, "Finite Element Modeling of Fatigue Crack Growth in Curved-Welded Joints Using Interface Elements," Journal of Structural Integrity & Durability, 1(3), 2005. 7. M.A. Wahab, J.H. Park, M.S. Alam and S. S. Pang, "Effect of Corrosion Prevention Compounds on Fatigue Life in 2024-T3 Aluminum Alloy," Journal of Material Processing Technology, 174, pp. 211-217, 2006. 8. M. A. Wahab and M.S. Alam, "The Significance of Weld Imperfection and Surface peening on Fatigue Crack Propagation Life of Butt Welded Joints," Journal of Material Processing Technology, 153-154, 2004, pp.931-937. 9. M.S. Alam and M.S. Baree, "An Estimation of Wave Spectrum by Applying Fast Fourier Transform," Journal-Institution of Engineers, Malaysia, 61(2), June, 2000. 10. M.S.

Alam and M.A. Wahab, "A New Technique for Modeling of Fatigue Crack Growth in Welded Tubular Joints and Structures," Proceeding of the International Mechanical Engineering Congress and Exposition, Florida, USA, 2005. 11. M.S. Alam and M.A. Wahab, "An Analysis of Fatigue and Micro Characteristics of Weld-Repaired Joints of Al-6061 Plates" International Conference on Computational & Experimental Engineering and Sciences, 2007, Miami, Florida. 12. M.A. Wahab and M.S. Alam, "Finite Element Prediction of Distortion and Residual Stress in Gas Metal Arc Welded Joint," Proceeding of 11th Annual International Conference on Composites Engineering, 2004. 13. M.S. Alam, M.A. Wahab and C.H. Jenkins, "Reverse Engineering of Naturally Compliant Structures, Computer Modeling in Engineering and Science, in press. 14. M.A. Wahab, M.S. Alam, S.S. Pang, Jerry Alan Peck and R.A. Jones, "Buckling of Polygonal Fiber Reinforced Polymer (FRP) Composite Tubes," Proceeding of 14th Annual International Conference on Composites Engineering, Boulder, Colorado, 2006. 15. M.S. Alam, Guoqiang Li and Walid R. Alaywan, "Experimental and Numerical Analysis of Flexural Properties of FRP Composite Sandwich Beam," Proceeding of 14th Annual International Conference on Composites Engineering, Boulder, Colorado, 2006. 16. M.S. Alam and M. A Wahab, "The Effect of Torsional Interaction of a Circular Porosity and a Solidification Crack on Fatigue Crack Propagation Life of Butt Welded Joints," Proceeding of 10th Annual International Conference on Composites Engineering, New Orleans, 2003. 17. M.S. Alam and M.A. Wahab, "The Significance of Weld Imperfection and Surface peening on Fatigue Crack Propagation Life of Butt Welded Joints," Proceeding of the International Conference on Advanced in Material and Processing Technology, Dublin, Ireland, 2003, pp.990-993. 18. C.H. Jenkins and M.S. Alam, "Use of Experimental Mechanics in Biomimetic Structural Design," Society of Experimental Mechanics Annual Conference, Milwaukee, WI, 2002. 19. M.S. Alam and M.S Baree, "A Regression Analysis for the Derivation of Wave Spectrum Formula," Proceedings of the Sixth Annual Paper Conference, Institute of Engineers, Bangladesh, 2000. 20. M.S. Alam and M.S Baree, "Prediction of Rolling Motion of a Ship at Hiron Point of the Bay of Bengal," Proceedings of the 3rd International Conference on Fluid Mechanics and Heat Transfer, Dhaka, Bangladesh, December 1999.

OTHER QUALIFICATIONS/EXPERIENCES Dr. Alam has six years research and thirteen years industrial experience. He has extensive technical and research intelligence, training and experience in structural mechanics, mechanical system design for oil & gas industries for more than fifteen years. He has proven capacity for employing Finite Element and classical stress analysis techniques in design evaluation of offshore and subsea structures. He has strong background on the design, analysis and evaluation of offshore platforms and subsea structures, equipment as per API, ASME, ABS, DNV and other standards. Dr. Alam has very strong proficiency in finite element analysis (static (linear, nonlinear), dynamic, Impact, Thermal, CFD) using ANSYS and ABAQUS. He did design and analysis of offshore and subsea product for BP, Exxon, Total, Murphy, Statoil, etc. oil companies.

SYNERGISTIC ACTIVITIES 1. Dr. Alam has received 2 research grants from two agencies to support his research prior to join at TAMUK. 2. Dr. Alam applied for several grants to several agencies prior to join at TAMUK: Defense Advanced Research Projects Agency (DARPA), Office of Naval Research (ONR), Louisiana Space Consortium (LaSPACE). 3. Dr. Alam has reviewed over 10 papers for six archival journals: Composites B: Engineering, Engineering Structures, International Journal of Damage Mechanics, Journal of Polymer Composite, Journal of Composite Material, Proceeding of the 2006 ASEE Gulf-Southwest Annual conference 4. He is an active member of American Society of Mechanical Engineers (ASME).

Introduction

The ability to visualize three-dimensional objects and their orthogonal views and manipulate those images is a cognitive skill vital to many STEM fields, especially those requiring work with computer - aided design (CAD) tools (Smith, 1964). Research suggests that well developed spatial skills of this type are critical to successfully advance in engineering and many other fields (Sorby et al., 2013). These types of spatial skills involve visualizing three-dimensional objects and perceiving their different orthogonal viewpoints if they were rotated in space. Virtual reality (VR) provides the ability to rotate the objects as well as experience immersive interaction in a virtual environment. Spatial reasoning has been widely studied and is known to be essential to higher-level thinking and creative processes. Spatial visualization skills are particularly important to the technical profession, such as engineering and computer science (Maier, 1994; Norman, 1994). Spatial skills are one of the strongest predictors of success in using the computer-aided design software (Hamlin, Borsma & Sorby, 2006). Research showed that the students with high spatial orientation scores were more likely to draw correct structures and diagrams (Pribyl & Bodner, 1987). Pictorially representing problems before beginning to work on calculations is particularly important as problems become more complex and additional factors (eg. Angles, forces) begin to play a role in the problems (Taasoobshirazi & Garr, 2008).

Review of the research on spatial orientation skill in STEM

Engineering students need to develop strong spatial orientation skills to represent and communicate their design ideas to others. These communication tools involve three-dimensional models of prototypes as well as their two-dimensional drawing representations. For example, when designing a motorcycle's air filter unit, a design engineer must be able to visualize how the air filter housing design matches the airflow intake to the carburetor. Mechanical engineers need to analyze how the tractor tires bear the load and act in various terrains on fields. Similarly, architectural engineers must visualize how plumbing system is structured to avoid complications at joints in the pipe grids. Condon & Schroeder (2005) stated that the spatial orientation skills of engineers were highly developed compared to other professions. Dakeev (2017) indicated that there is a need to structure CAD courses with virtual reality since the generation Y is more involved with the virtual 3D environment (such as PC or Console games) compared to their counterparts, who had significantly more exposure on hands-on projects. Additionally, the researchers stated that it is possible to assess students' sustained attention and inhibition with virtual reality (Dakeev et al., 2018). Riera (2016) developed a virtual home to recruit students to STEM fields. In their Home I/O design, the researchers provided various electrical applications in a smart house, where one could switch between renewable and utility energy at various times of day to simulate house's energy consumption (Riera, Empirin, Annebicque, Colas & Vigario, 2017).

Methodology

A group of computer aided-design students (freshmen and sophomore) participated in this study. A total number of thirty-five (4 female and 31 male) students completed a spatial orientation test online at the beginning of spring 2017 and fall 2017 semesters. The spatial orientation test was used to explore students' spatial orientation ability and was comprised of 10 questions, where the participants must select the right orientation of a given part. Each class, the instructor provided a three-dimensional representation of a part in the virtual environment for students to analyze before the start of the class (Figure 1).

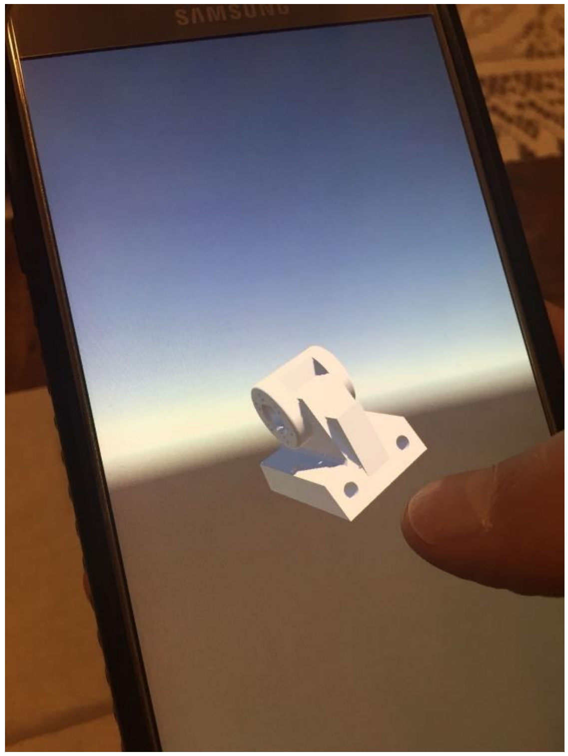

Figure 1. Analysis of a three-dimensional model for computer aided design class

The experimental parts (Figure 1) were developed in Creo Parametric from their orthogonal drawings. When the students were presented with the 2D drawing details, successful modeling of the part was usually accompanied with additional clarification questions such as: “What is the dimensions of XXX feature”, or “Where exactly this hole is located”. With the development of virtual environment, which represents the 3D model in a game form, the students could analyze the part and select the right views that represented the part for modeling. This way, the students could analyze how various features and dimensions of a part were interrelated with each other, thus, improving student spatial orientation skills. The virtual world for the 3D model analysis was developed with Unity Engine software. However, Unity and Creo Parametric are not compatible and the Creo exported file types are not recognized by Unity. Therefore, the creo part files were exported to stereolithography (stl) files, imported to 3D Studio Max, and exported to object (.obj) files, which can be imported into Unity. The newly developed virtual environment must be tested and analyzed with either Oculus Rift or HTC Vive and generated for phone compatibility.

The students downloaded the phone-compatible file, installed on their phone (android and iOS) and visualized with a VR headset (Figure 2).

Figure 2. Analysis of three-dimensional objects in a virtual environment

There are two different ways to analyze a virtual part on a smartphone: 1-controlled, installation on the phone and rotating via touch sensors of the phone, and 2-uncontrolled, where the observer has no control over the environment but watch how the scene is animated to take the observer on a virtual tour around the object (part). Both methods were provided for students, however, these methods were not compared between each other for more effectiveness.

Data analysis

The first computer-aided design course in the spring 2017 semester had 19 students that participated in the study. Paired sample t-Test resulted that the students were able to find the correct orientation after they analyzed the part (Pretest Mean = 1.42 < Posttest Mean = 8.58) within the virtual environment (Table 1).

Table 1. Paired Sample t-Test Descriptives for Freshmen and Sophomore Engineering Students

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pretest	1.42	19.00	0.69	0.16
	Posttest	8.58	19.00	0.84	0.19

Additionally, SPSS t-Test result (Table 2) indicates that there is a significant difference (p value=0.00 < alpha level 0.05) between the test results when the students were exposed to the virtual analysis of the 3D part model with 95% confidence interval.

Table 2. Paired Sample t-Test Mean Comparison to Compare the Influence of a VR

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Pretest - Posttest	-7.16	0.83	0.19	-7.56	-6.76	-37.40	18.00	0.00

From both tables 1 and 2, it can be observed that the computer-aided design students were able to select the correct answer for spatial orientation test more frequently when they were exposed to the virtual environment to analyze parts. Although the t-Test analysis resulted that there were significant differences between the pretest and posttest average means of the scores, the correlation table (Table 3) shows that was a slight correlation between the two scores.

Table 3. Correlation between the Pretest and Posttest outcomes for Spatial Orientation

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Pretest & Posttest	19	.418	.075

Since there were only 19 students in the spring 17 CAD course, the researchers needed to investigate more to see if the involvement of a VR tool in the 3D modeling class would improve the spatial orientation skills of freshman and sophomore engineering students. The same procedure was replicated in the fall 2017 semester in the ITEN 1311: Introduction to Computer Aided Design course, where the total number of 16 students participated in the study. The introduction to CAD is a prerequisite course to Advanced Graphics and Modeling, which is offered in spring semesters. Therefore, the registered students in the fall semester course did not overlap with the results from the spring 17 analyses (Tables 1, 2, and 3).

Table 4. Paired Sample t-Test Descriptives for Freshmen and Sophomore Engineering Students

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pretest	6.06	16.00	2.82	0.70
	Posttest	9.19	16.00	0.98	0.25

The descriptive statistics on Table 4 shows that the posttest mean value of students was slightly higher than the pretest, meaning that the interjection of virtual reality into the model analysis improved students' spatial visualizations.

Table 5. Paired Sample t-Test Analysis for the Influence of a VR in Fall 2017 Semester

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pretest - Posttest	-3.13	3.18	0.80	-4.82	-1.43	-3.93	15.00	0.00

The paired sample t-test between the mean values at the beginning of the semester with and without the introduction of VR environment, to analyze virtual parts, indicated that there was a significant difference (p value=0.00 < 0.05 alpha level) between the test scores. This result shows that the students understand the structures of the 3D model when they inspect it in the virtual environment. It should also be noted that the descriptive statistics produced a higher mean value for the posttest boxplot as well as one extreme outlier for the posttest for the spring 2017 data points. The reason for this outlier was calculated inaccurately since SPSS multiplied by 1.5 IQR (Hoaglin & Iglewicz, 1987). Therefore, the researchers decided to review the data point and concluded the histogram of the data was normal for the posttest data, and the data score 6 was not an outlier (Figure 3).

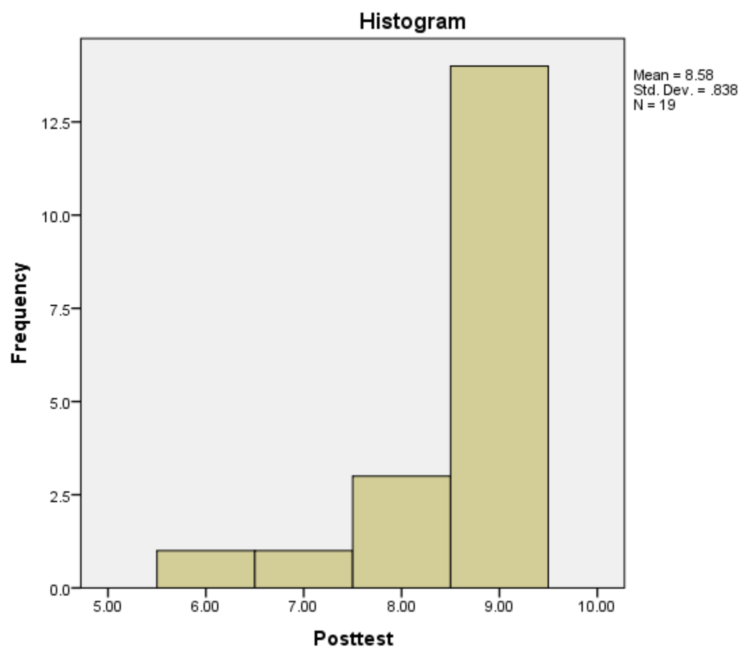

Figure 3. Investigation of an Outlier score (6) for the Spring 2017 posttest data

Discussion

Although the project outcome revealed important data in significant improvement of spatial orientation skills in freshman and sophomore engineering students, cost of the equipment may challenge the practicality of the project. However, the augmented reality (AR) based project may justify the practicality of the project, especially when the AR can be used by both Android and iOS devices, which are excessively available in the possession of the students. Therefore, a downloaded app on the phone can project the three-dimensional representation from a 2D drawing. As an example, downloading "Midterm_AR" app (Figure 4) from Google's play market and directing the android phone's camera on the two-dimensional drawing (Figure 5) will generate the 3D illustration of the part model. Consecutively, in addition to spatial orientation skill development in early engineers, non-engineering personnel may be able to visualize the 3D features of a prototype part before it is ordered for manufacturing.

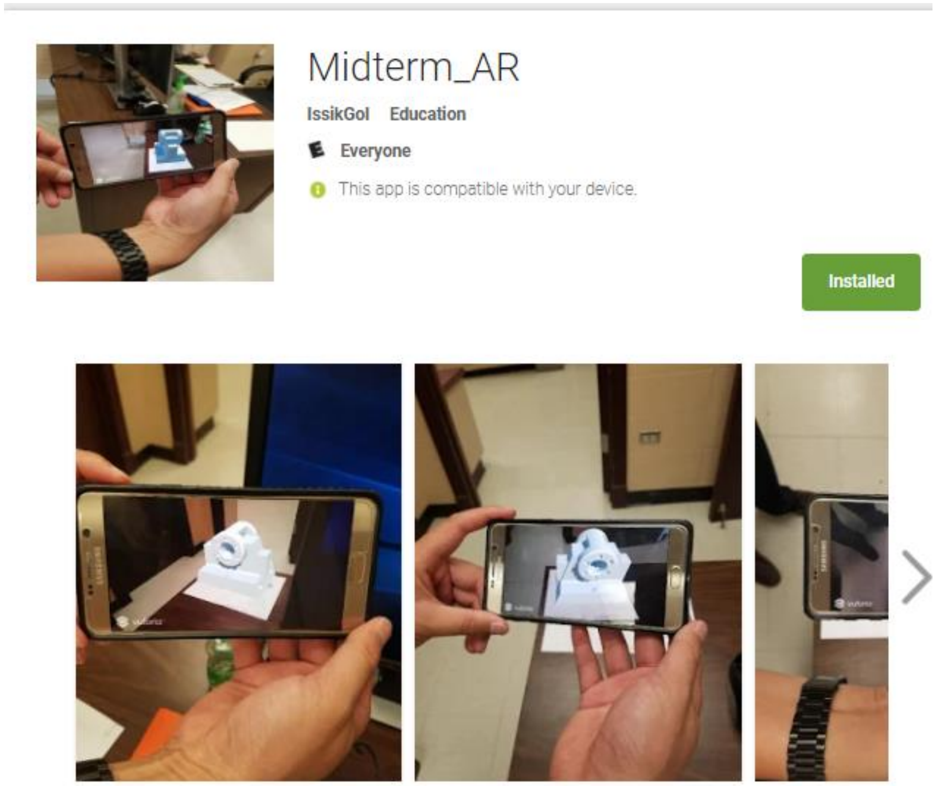

Figure 4. Midterm_AR app in the Google's play store for Android devices

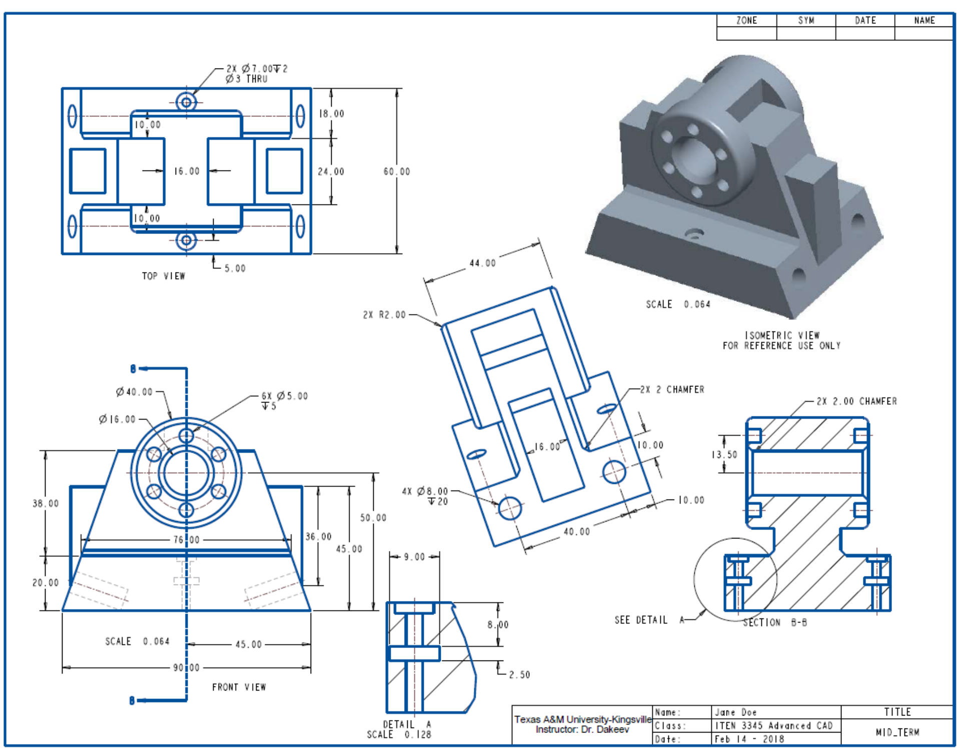

Figure 5. Target drawing for the AR app to visualize the part in 3D representation

Conclusion

The purpose of this study was to investigate how a spatial orientation skill is influenced, for freshman and sophomore engineering students, when a virtual environment is introduced to analyze three - dimensional models. The analyzed data, from two computer aided-design courses in spring 17 and fall 17 courses, showed that there is a significant improvement (Pretest Mean = 1.42 < Posttest Mean = 8.58 for the spring 17 semester, and Pretest Mean = 6.06 < Posttest Mean = 9.19 for the Fall 17 semester) when the students observed the 3D parts in a virtual environment. We can conclude with 95% confidence interval that the students understand the assignment expectation when they are given the opportunity to observe the three-dimensional part prior to the start of the project. The researchers believe that the restructuration of an introductory CAD course could help instructors to engage and motivate students and train skilled drafters/modelers with less effort.