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Use of Virtual Reality Tools in an Undergraduate Mechanical Engineering Manufacturing Course

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Kris Frady is an Assistant Professor in the Departments of Educational and Organizational Leadership and Development and Engineering and Science Education at Clemson University and Faculty Director for Clemson University Center for Workforce Development (CUCWD) and the National Science Foundation Advanced Technological Education Center for Aviation and Automotive Technological Education using Virtual E-Schools (CA2VES). Her research and experiences include implementation of digital learning solutions, development of career pathways including educator professional development, and analysis of economic development factors impacting education and workforce development. Kris earned an Ed.D. in Curriculum and Instruction in Education Technology from the University of Florida and also holds business and teaching degrees from Clemson University and the University of South Carolina. Kris has previously worked as a professional corporate trainer, as an instructor at a two-year institution, and as a career and technology education teacher at the high school level. Kris and the CUCWD/CA2VES team aim to develop an exchange which will help identify, understand, and elevate best practices; facilitate peer learning and deepen knowledge; spark replication and advancement across regions; and inform long-term public investment in talent development through research and educational resources.

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Dr. Kapil Chalil Madathil's area of expertise is in applying the knowledge base of human factors engineering to the design and operation of human-computer systems that involve rich interactions among people and technology. His research covers the entire spectrum of system design: from identifying the user needs to designing and developing systems that inform and motivate user behavior and empirically evaluating the efficacy of these interventions. He draws on qualitative and quantitative methodologies including ethnography, contextual inquiry, surveys and controlled behavioral experiments to understand how humans perceive, make sense of, and interact with complex human-machine systems.

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Rebecca Hartley has spent the past eighteen years working in higher education administration in the areas of undergraduate admissions, graduate admissions, academic records, and student affairs. She holds a Ph.D. in Public Administration and Public Policy from Auburn University. Prior to joining the Clemson University Center for Workforce Development as the Director of Pathways, she served as Director of Graduate Admissions & Records at the University of Montevallo in Alabama. Her research interest and expertise focuses on citizen public opinion as it relates to federal and state public policy. Additionally, her research focus includes how outside political interests affect policy agendas and specifically policy implementation. She currently serves as the Director of Operations for the Clemson University Center for Workforce Development and the Chief Workforce Officer for the American Robotics for Manufacturing Institute.

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JOHN WAGNER joined the Department of Mechanical Engineering at Clemson in 1998. He holds B.S., M.S., and Ph.D. degrees in mechanical engineering from the State University of New York at Buffalo and Purdue University. Dr. Wagner was previously on the engineering staff at Delphi Automotive Systems and Delphi Delco Electronics (formerly Delco Electronics as a subsidiary of General Motors Hughes Electronics) designing automotive control systems. His research interests include nonlinear and intelligent control systems, dynamic system modeling, diagnostic and prognostic strategies, and mechatronic system design with application to turbines and automobiles. He has developed the multi-disciplinary Rockwell Automation Mechatronics Educational Laboratory which features hands-on robotic, programmable logic controller, electronic, and material handling experiments. He is a past Associate Editor of the ASME Journal of Dynamic Systems, Measurement, and Control and IEEE/ASME Transactions on Mechatronics, respectively. Dr. Wagner is a licensed Professional Engineer and Fellow of the American Society of Mechanical Engineers.

Dr. Anand K. Gramopadhye, Clemson University

Dr. Anand K. Gramopadhye's research focuses on solving human-machine systems design problems and modeling human performance in technologically complex systems such as health care, aviation and manufacturing. He has more than 200 publications in these areas, and his research has been funded by NIH, NASA, NSF, FAA, DOE, and private companies. Currently, he and his students at the Advanced Technology Systems Laboratory are pursuing cutting-edge research on the role of visualization and virtual reality in aviation maintenance, hybrid inspection and job-aiding, technology to support STEM education and, more practically, to address information technology and process design issues related to delivering quality health care. As the Department Chair, he has been involved in the initiation of programmatic initiatives that have resulted in significant growth in the Industrial Engineering Program, situating it in the forefront both nationally and internationally. These include the Online Master of Engineering in Industrial Engineering Program, the Endowed Chairs Program in Industrial Engineering, Human Factors and Ergonomics Institute and the Clemson Institute for Supply Chain and Optimization and the Center for Excellence in Quality. For his success, he has been recognized by the NAE through the Frontiers in Engineering Program, and he has received the College's Collaboration Award and the McQueen Quattlebaum Award, which recognizes faculty for their outstanding research. In addition, Dr. Gramopadhye serves as Editor-in-Chief of the International Journal of Industrial Ergonomics and on the editorial board for several other journals.

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Abstract

The demand for highly skilled engineers in the global manufacturing industry continues to rise as technology grows ever more complex. The advent of networked computerized machines requires a level of technical competence that integrates theory and practical expertise. Companies expect their entry level graduates to have a thorough understanding of the basic manufacturing concepts and experience with handling common equipment and processes. This paradigm presents a challenge as university programs may lack relevant production equipment and curriculum space for laboratory credit hours. Virtual Reality (VR) can counter this impasse since it is relatively inexpensive and can be modified to meet the demands of an ever-changing industry. Using VR, instructors can demonstrate manufacturing processes visually and instruct students on how to handle the equipment within a typical corporate setting. The Center for Aviation and Automotive technology using Virtual E-Schools (CA^2VES) in collaboration with Center for Workforce Development (CWD) at Clemson University has assembled an online repository of virtual reality based teaching supplements for instructors at technical colleges and universities to help prepare students in the aviation, automotive, and manufacturing fields. To evaluate the effectiveness of the prepared material, a pilot study was conducted at Clemson University in a junior level manufacturing processes course. The analysis shows that there was a significant increase in the student performance after the material was implemented. The class instructor stated that the students were more confident in handling equipment and understood the target processes better. However, one concern is the student participation level given that the materials are optional in the class.

I. Introduction

University education involves teaching and training students to be proficient in their respective fields, and successfully embrace challenges that may present themselves on the job. Accordingly, students are taught key skills that may be immediately required in the corporate world along with fundamental concepts that supplement their primary roles in the workplace. This diversified training helps students in adapting to different types of job roles that may be required of them after graduation. Recently, a greater emphasis is being placed on select skills that are referred to as employability qualifications. Azami et al.[1] studied various Asian employers' perception of these employability skills and found that even though most employers do agree on a few skills being classified as employability skills (e.g., communication, reasoning), their opinion varied significantly on what the other skills should be. It was found that each industry, country, and region have different views about which skills are most needed in new graduates. As an example, Male reported that different countries have different levels of importance regarding language as an employability skill.[2] Moreover, even if these skills could be properly defined, there is no definite way to reach a consensus as to the degree of influence of each of these skills towards employability.[3] However, these skills can be broadly classified into three categories - technical skills, interpersonal skills, and commercial awareness.[4] Of these categories, technical skill is typically gained through actual hands on experience in the laboratory. This is a challenge since colleges and universities, in some instances, may lack the facilities and infrastructure for a robust laboratory curriculum and instead rely on classroom lectures and videos.

The learning experience for an undergraduate student in a nominal mechanical engineering curriculum for a manufacturing processes class is shown in Figure 1. At the junior level, the student may receive instruction about manufacturing processes through in-class lectures and online videos. At Clemson University, the senior year offers students an opportunity to work with equipment in a laboratory (ME 4440). The material being developed by CA^2VES intends to bridge this gap and provide the students with an intermediate pathway to visualize and understand the fundamental theory. The consultation of industry experts in designing university course structure helps to ensure that students are prepared for work assignments after graduation. Most researchers agree that the involvement of industry specialists in setting up and evaluating the university course curriculum is beneficial.[4,5] This can be attributed to the visibility of industry trends and standards by the external review boards, thus involving a broad range of stake holders in the course planning that ensures students will obtain key skills to help them prepare for employment.

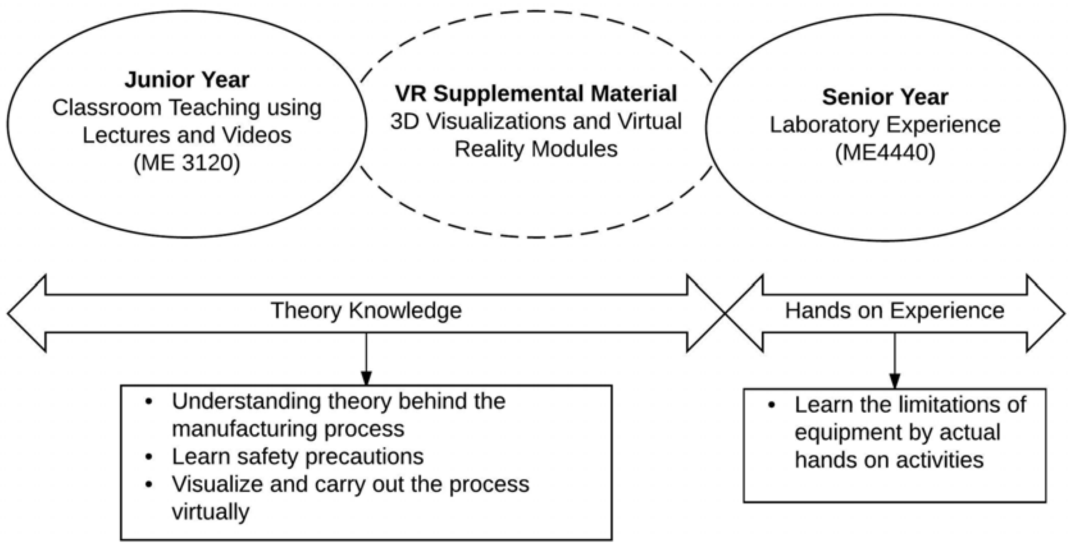

Figure 1 - Manufacturing learning experience at Clemson University

To meet the expectations of an ever-evolving industry, it is necessary to upgrade and adapt suitable teaching methods, equipment, and tools. For this, a cost effective and highly versatile toolset is required that can be quickly formulated to meet design challenges. Virtual reality can be molded to suit a wide variety of applications and changes in an inexpensive and efficient manner. With the ability to simulate literally any kind of activity in the virtual world, the possibilities are endless for this technology. Whether it is just a simple simulation of a mechanism or a highly complex fluids problem, it can be visually and mathematically simulated using VR. However, the benefits of VR are not limited to just its flexibility. The most crucial advantage of using VR as a teaching aid is that it boosts student learning performance through visual representation of complex concepts which they might have found hard to grasp otherwise.[6,7] Apart from these, its other advantages include assisting in research, increasing outreach to a wider audience remotely, and making the learning environment safer by eliminating risks. Weber et al. reported that using virtual instruments helped in establishing a complete state-of-the-art laboratory from a basic concept in just 18 months.[8] Though they did not use a completely interactive virtual environment, such as the one developed at Clemson University, they significantly reduced student learning time in acquiring key concepts and used that extra time in the laboratory to teach practical skills. The distance learning advantage of using virtual reality was also demonstrated by Deniz et al. through their remote lab project using virtual tools.[9] It is important to note however that the CA²VES virtual reality toolset is more immersive and does not require any specialized equipment as used by the researchers. Hence it is expected to be easier to implement the VR curriculum at a broader scale and achieve improved results in comparison to earlier efforts.

In consideration of the many advantages of using VR as a teaching aid, a comprehensive standalone VR based teaching toolset was created to advance education in the automotive, manufacturing, and aerospace engineering fields. The material consists of a wide array of content ranging from e-books and lecture videos to fully immersive virtual environments of laboratories and workshops (refer to Figure 2). All the developed materials, available on the website www.educateworkforce.com only require a standard laptop with an internet connection to access. The target audience for the content are universities, technical colleges, and industry training programs but can also be accessed by individuals who intend to continue their education as the material is self-paced. For the pilot study, the manufacturing portion of the materials were selected since they best aligned with the target course. A series of self-contained modules were provided as an added supplement for the junior level undergraduate ME 3120 course to evaluate the overall effectiveness. More details about the VR material development strategies and methods have been discussed by the team in various conference and journal papers.[10,11,12,13]

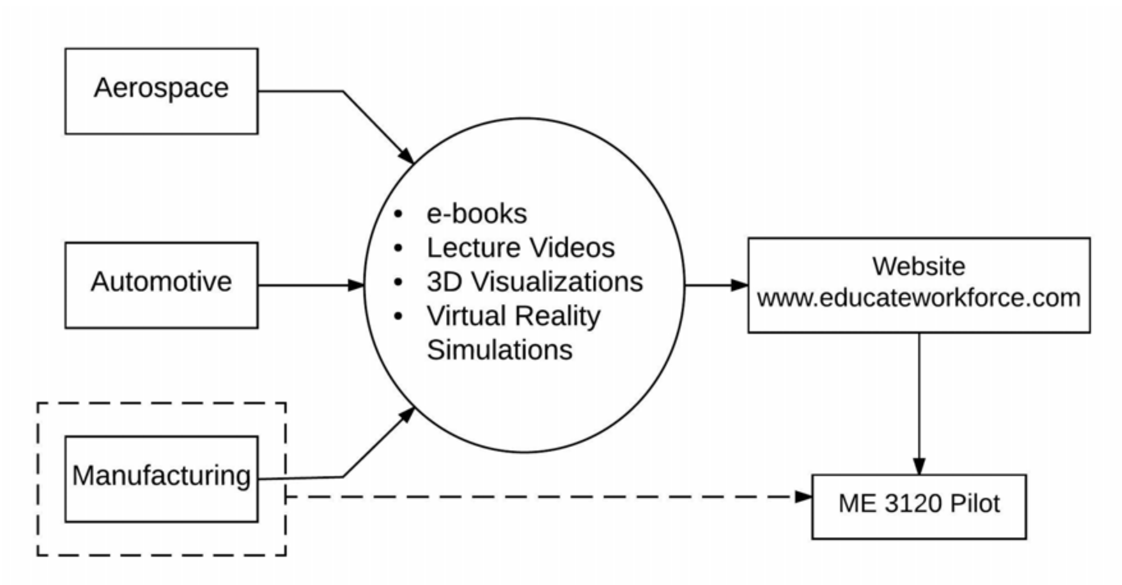

Figure 2 - Summary of course materials developed by CA²VES

II. Methodology for Implementation and Evaluation of Virtual Reality Materials

The successful deployment of a new curriculum should include the evaluation through controlled case studies. A pilot study to assess the material was started in the Fall 2014 semester in the Mechanical Engineering Department at Clemson University. The junior level undergraduate course "Manufacturing Processes and their Application" (ME 3120) provides students an overview about common industry manufacturing processes. The instructor for this course used a standard grading system of 90-100, A; 80-89, B; etc. Special emphasis was given in developing the supplemental e-learning material in a manner that would help students grasp the basic concepts while simultaneously practicing typical applications within a virtual industrial environment. For instance, the module for machining operations features a fully functional CAD equipment models (e.g., grinding machine) placed in a simulated manufacturing plant that was modelled to look like the actual conditions that might be encountered on the shop floor (refer to Figure 3 and Figure 4). This approach helps students learn about facility safety procedures while also introducing machine functionality.

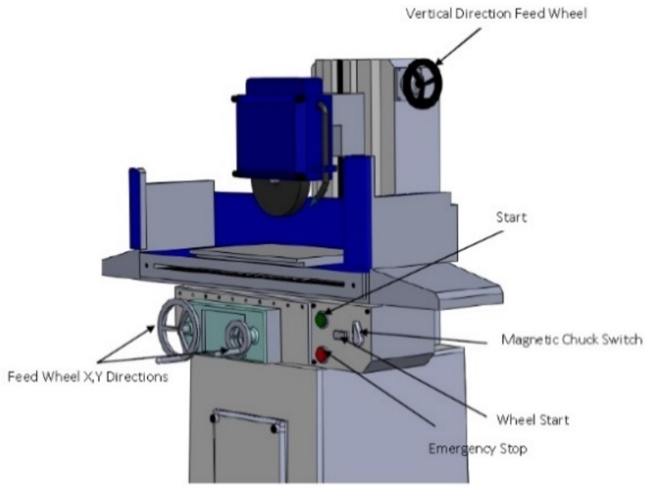

Figure 3 : CAD model (with labels) created for demonstrating grinding operation

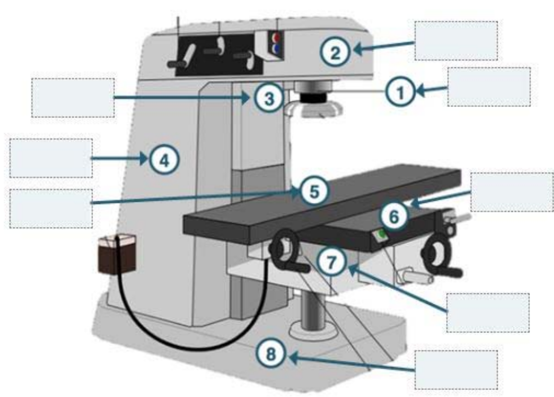

Figure 4 -CAD model (fill in the label blanks) created for demonstrating milling operation

The metrics to evaluate e-learning material impact included the students' module test scores, course score, and their university Grade Point Averages (GPA). The course score and GPA data from the previous two semesters prior to Fall 2014 offered a "before" view of the course. The instructor elected to offer some extra credit for those who completed a module to ensure that it would not adversely affect the grades in case problems arose with the material. The student received an extra credit of 0.71% per module upon successful completion with a score of 80% or above in the assessment section of the module. If a student completed all modules in ME 3120, they received 5% added to the final score. This was later increased to 1% per module from spring 2016 for a total of 7% added. Table 1 lists all the modules that were available for the students enrolled in the courses.

Table 1 : Manufacturing processes lab modules

Module	Title
1	Introduction to Manufacturing and Production
2	Properties of Engineering Materials
3	Engineering Materials
4	Production Processes
5	Machining Operations
6	Tool & Equipment Operation: Lathes
7	Special Processing

III. Presentation and Discussion of Student Learning Performance

The parameters chosen for assessing the learning impact of the e-learning materials were the student's course grade and overall university GPA. The university GPA was taken as a normalizing factor whereas the subject grades presented the student's performance in the course. The usage of the material was quantified based on the number of learning modules completed. The course grades and the overall GPA used a 4-point scale, with A being 4 and D being 1. A total of six semesters were taken into consideration with the initial two semesters being ones in which no VR material was used. This was to establish a baseline for comparison purposes. Table 2 shows the distribution of the grades and GPA along with the average number of modules completed by each grade category. The performance of the students in the course was analyzed for each of the grade categories from A through C whereas the students who failed the class with a D were not considered as part of the analysis since they constituted a very small percentage of the class. Figure 5 and Figure 6 display the study findings which are summarized in Table 2.

To evaluate student performance trends, each grade category has been analyzed individually over six semesters. Figure 5 shows a considerable performance spike during the first semester of material implementation in terms of students getting an A grade. However, it is important to note that the class size was considerably less during this semester and continued to rise later. The average number of modules completed by each student during this semester was 4.4 which adds a total extra credit of about 3%. Successive semesters saw a more normalized grade distribution as the instructor restructured the course to better accommodate the supplementary materials. The GPA trend on the other hand was relatively linear in each grade category suggesting that performance in the course was not related to the student's performance at the university level. The most interesting observations however can be viewed in Figure 6. The left-hand Y-axis represents the course score and the right-hand Y-axis represents the total number of modules completed by each individual student. As a general trend, students with better grades completed more modules, although many students in the lower grade category also completed more modules specially when they needed just a few more points to improve their grade from a C to B and B to A. As an example, the distribution trend for fall 2015 shows that 9 students (18%) with an A grade chose not use the material in contrast to almost 30 students (69%) from the B grade category. However, it is important to note that the weightage of assignments was much higher than the modules and thus the effect of the extra credit did not have a major impact on student's grades.

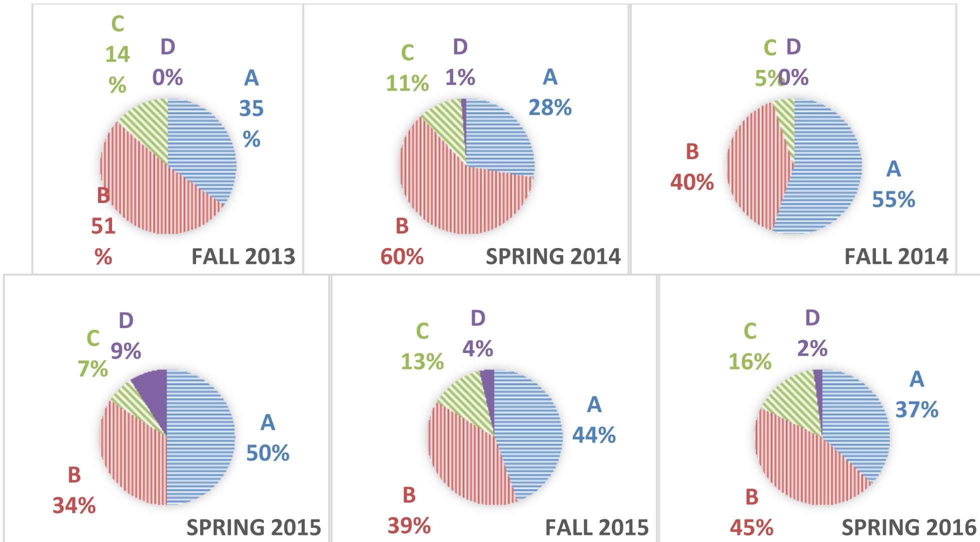

Figure 5 : Grade distribution for ME 3120 over a six-semester period

Table 2 : Distribution of Student Course Grades for ME 3120

Semester (Total Students)	Student Class Grade	Number of Students	Average Number of Modules Completed	Average Student GPA
Fall 2013 (95)	A	33	N/A	3.46
	B	49		2.98
	C	13		2.74
	D	-		-
Spring 2014 (75)	A	21	N/A	3.46
	B	46		3.16
	C	8		2.71
	D	1		2.51
Fall 2014 (38)	A	21	4.4	3.45
	B	15	2.5	2.83
	C	2	0	2.79
	D	0	0	0
Spring 2015 (88)	A	44	4.5	3.48
	B	30	2.9	3.04
	C	6	2.3	2.57
	D	8	1.6	2.35
Fall 2015 (110)	A	49	3.8	3.53
	B	43	0.8	3.03
	C	14	1.1	2.78
	D	4	0	2.05
Spring 2016 (95)	A	35	3.6	3.52
	B	43	3	2.97
	C	15	2	2.68
	D	2	3	2.24

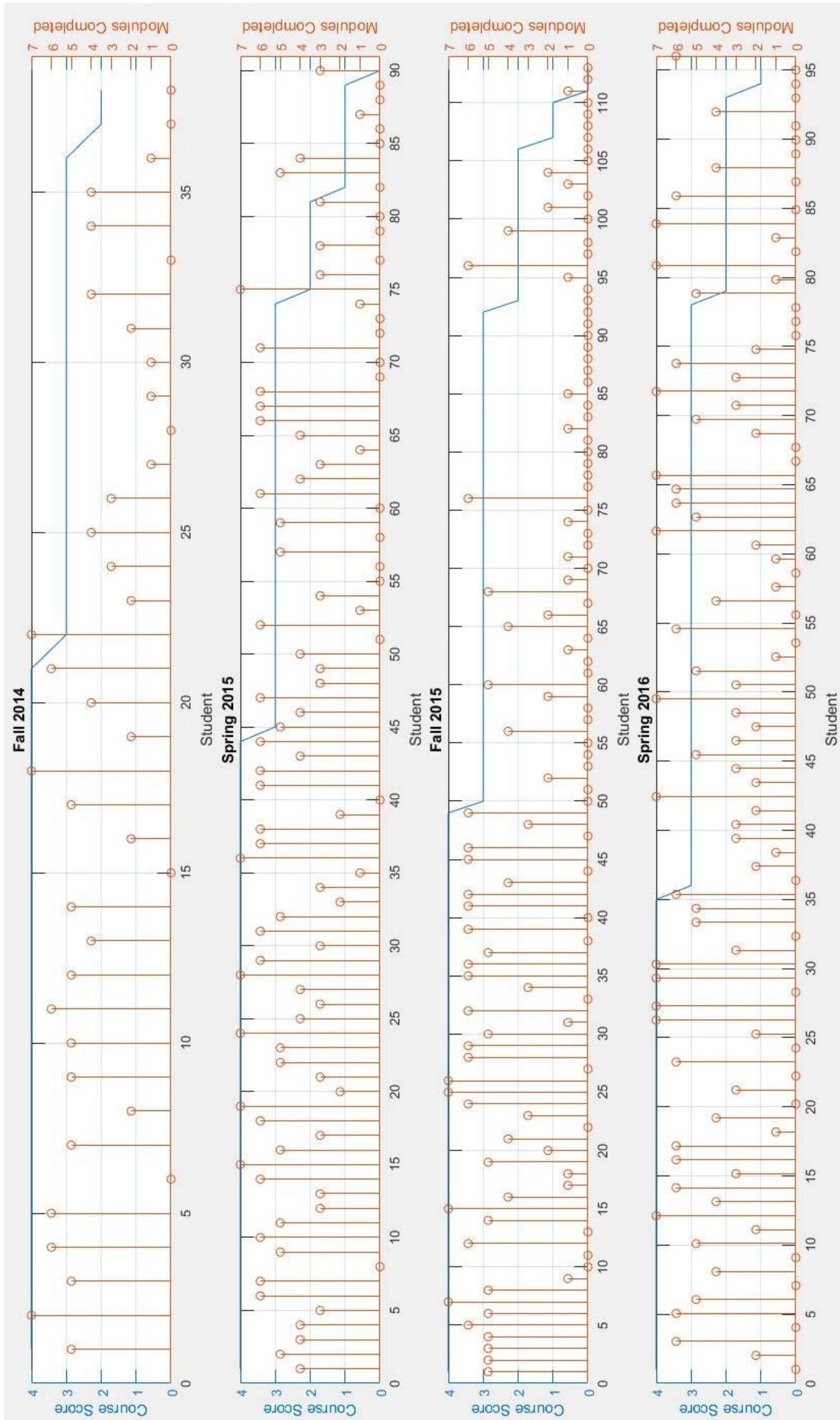

Figure 6 - Course scores and completed modules by each individual student for ME 3120

IV. Instructor Feedback

An important task in exploring the impact of the e-learning materials was interviewing the course instructor. Per the teacher, the most important take away from these materials was the high quality interactive virtual simulations. These visuals helped the instructor demonstrate to the students how the processes and equipment work, and engage the class in the discussion despite the lack of proper equipment. The teacher's approach prior to the VR modules was to use YouTube® videos in class which were generally of a lower quality. Furthermore, the class performance was also somewhat related to the enrollment size since it is harder to give ample attention to students individually. But this problem was reduced using the online developed materials since they are designed to be used with little, or no, help from an instructor. Also, the teacher felt that the extra credit remained the main driving force for the use of the material despite all its advantages. However, one drawback reported regarding the material was the extra effort to use a different platform to upload the grades into the university registrar's database.

V. Conclusion

The availability of a "hands-on" experience when teaching manufacturing processes can improve the overall student learning experience. In situations where production equipment is not available, virtual reality offers an alternative visual representation of the processes. A pilot study to evaluate the use of virtual reality based learning materials to supplement the classroom lectures was investigated. A series of seven modules were introduced into the junior year manufacturing course. The student performance was directly related to the amount of material completed by the individual, with better performing students completing more material in general. Although the supplemental modules were not mandatory, students did complete them to enhance their knowledge. The instructor's comments reported the material was of high quality and using it as a teaching supplement assisted in handling a bigger class efficiently and helped the students perform better. Future will focus on more direct assessment measures to evaluate the e-learning materials in the classroom using surveys.

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