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An Introduction to the CLICK Approach: Leveraging Virtual Reality to Integrate the Industrial Engineering Curriculum

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Abstract

This work introduces a new approach called Connected Learning and Integrated Course Knowledge (CLICK). CLICK is intended to provide an integrative learning experience by leveraging Virtual Reality (VR) technology to help provide a theme to connect and transfer the knowledge of engendering concepts. Integrative learning is described as the process of creating connections between concepts (i.e., skill and knowledge) from different resources and experiences, linking theory and practice, and using a variation of platforms to help students' understanding. In the CLICK approach, the integration is achieved by VR learning modules that serve as a platform for a common theme and include various challenges and exercises from multiple courses across the IE curriculum. Moreover, the modules will provide an immersive and realistic experience, which the authors hypothesize, will improve how the students relate what they learn in a classroom, to real-life experiences. The goals of the CLICK approach are to (i) provide the needed connection between courses and improve students' learning, and (ii) provide the needed linkage between theory and practice through a realistic representation of systems using VR. This work presents the results from an initial usability test performed on one of the VR modules. The results from the usability test indicate that participants liked the realism of the VR module. However, there are still some areas for improvement, and future work will focus on assessing the impact of the CLICK approach on students' learning, motivation, and preparation to be successful engineers, areas which could translate to a STEM pipeline for the future workforce.

1. Introduction

The typical curricula for students majoring in engineering involve a set of courses that are ordered in a sequence in which each course provides the students with the required knowledge to take the next course in this sequence [1]. The structure of the Industrial Engineering (IE) curriculum is no exception. The courses in these curricula are usually taught by different instructors. This traditional course-centric curriculum structure is limited in its ability to establish the connection between fundamental topics and real-world problems [1], [2]. The lack of this connection could be due to time and context separation [2].

The lack of connection and understanding could impact students' attrition rates. Engineering graduate rates in the US have been consistently around 50% over the last 60 plus years [3]–[8]. Many factors contribute to these low rates, such as classroom and academic climate, grades and conceptual understanding, self-efficacy and self-confidence, high school preparation, interest and career goals, and race and gender [9]. The classroom environment and academic climate may include factors such as the lack of feeling engaged or differences in teaching styles. Grades and conceptual understanding means difficulties in understanding concepts and low grades that may drive students away [9]. Therefore, the current curriculum structure needs to be changed in order to remedy, or at least reduce, the effect of these factors.

Concepts taught in different courses are usually connected. The knowledge in a prerequisite course is needed for the student to understand the more advanced knowledge in the next course. For example, in the IE major, concepts such as probability density functions and distributions (e.g., how to collect data, what they mean, and how to fit these distributions) are taught in fundamental statistics and probability courses in the sophomore or junior year and are in many courses that follow in the senior year. Courses such as manufacturing systems design and analysis (e.g., factory physics), discrete-event simulation (e.g., arrival times distribution), and stochastic operations research (e.g., stochastic inventory management) all need statistical and probability knowledge. Traditional teaching methods are limited in their use of complex and real-life examples within a classroom. Moreover, the time and context separation break continuity and chances to connect the knowledge across the courses.

In light of existing limitations, the authors introduce the framework for a new approach to integrating the knowledge in the IE curriculum. This approach is called Connected Learning and Integrated Course Knowledge (CLICK). The approach leverages VR technology to create learning modules to help provide a theme to connect and transfer the knowledge across the IE curriculum. Figure 1 shows the differences between the traditional curriculum structure and the new structure with the CLICK approach. The CLICK approach uses VR technology as a platform to build a virtual system. The virtual system acts as the central theme (i.e., single vehicle) that transfers the knowledge from one course (i.e., destination) to another. On the other hand, the traditional approach does not have a common theme (i.e., different vehicles). Additionally, the knowledge is disconnected due to time and context separation.

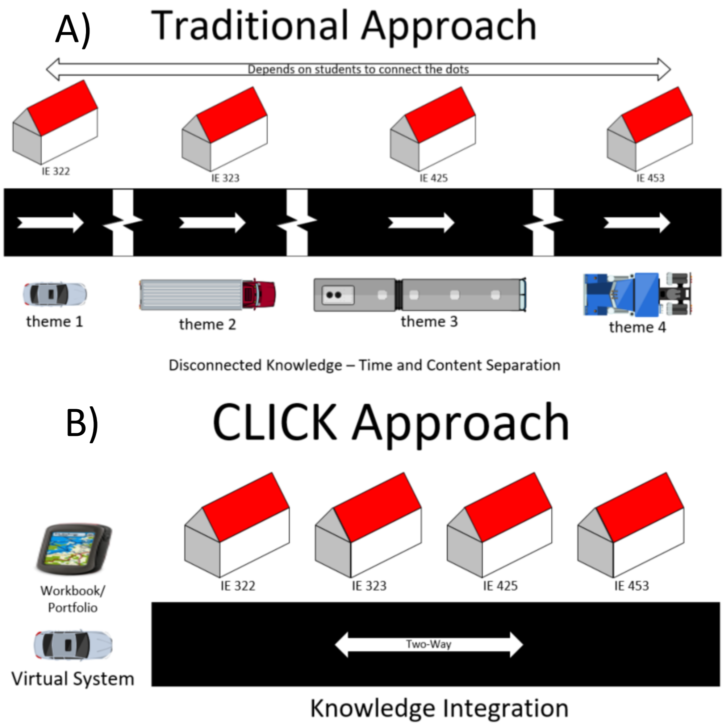

Figure 1. The flow of the curriculum: (A) Traditional approach, (B) CLICK approach

In this work, the literature regarding curriculum integration and the use of VR technology in educational environments is explored in section 2. Subsequently, the proposed approach and the developed VR teaching modules are introduced in section 3. In addition, in section 3, the student target population is introduced, and the results from the questionnaires completed by the control group are presented. Moreover, section 4 presents the results and discussions from the usability analysis performed. Finally, the conclusion and future works are presented in section 5.

2. Literature Review

Curriculum integration aims to make individual courses integrated parts of a whole, connected, and have a common theme of knowledge [10]. The connection between these courses should go beyond traditional concurrent and prerequisite sense. The connection should aim to achieve a common goal. A limited number of studies have investigated the overall integration of a curriculum [1]. However, a growing body of knowledge that studies the idea of integrating courses across the entire curriculum has been emerging. The goal is not to integrate all the content in all courses. The idea is to have a common theme across the courses versus focusing on teaching courses as individual separated entities [1].

The current engineering curricula provide a wide range of courses. These courses are connected and taught by different instructors. The instructors of the courses expect that the students will be able to transfer the knowledge between courses and be able to connect the concepts as well. While this is designed in the current structure of the engineering curricula, it is not sufficiently happening as expected [1]. Maciejewski et al. [2] suggest that the responsibility of transferring the knowledge between courses and figuring out the connection should not be on the students but rather, on the curriculum.

Many studies have investigated the impact of curriculum integration on students' performance, particularly in the Mechanical Engineering curriculum [11]–[13]. For example, Evans [12] reported improved grades as a result of curriculum integration. Felder et al. [11] reported increased student satisfaction. Olds & Miller [13] reported positive reactions from students. Some studies investigated curriculum integration in the first two years of the Mechanical Engineering curriculum by implementing a four-course sequence. The researchers of these studies measured the effect of curriculum integration on students' motivation to stay in school, helping non-traditional students in their learning, and increasing knowledge retention of the material [14], [15]. Curriculum integration resulted in an overall improvement of students' performance over a three-year period [14].

Computers have been used as instructional aids since the mid-40s [16]. VR technology has been in use in many domains including the military, education, and training [17]. There are many advantages of using VR in learning applications [18]. VR technology provides the sense of "being there" [19] and creates a "first person" experience [20], [21], especially when used to simulate a real-life experience. VR also provides a relatively inexpensive and less risky alternative compared to expensive or dangerous situations that might happen by interacting with actual systems [22], [23]. Some universities have tried to build physical manufacturing systems to teach and train students on manufacturing operations. For example, the Department of

Industrial and Systems Engineering at Auburn University created a laboratory called automotive manufacturing systems lab [24]. In this lab, students build Lego vehicles and learn about Toyota production system principles. While these labs provide hands-on experiences, they need a considerable amount of space (4,000 ft^2)[25] and require at least 18 students to run an experiment [26]. The authors believe that these systems are relatively expensive to build as well as to maintain compared to most VR technologies. Moreover, they are not portable, i.e., limited to residential courses and cannot be used with online learning. Nonetheless, VR technology can be used to build intricate virtual systems that resemble real-life systems [18], [27]. VR technology provides a suitable platform in the educational settings for learners to participate in the learning environment with a sense of being part of it. VR enhances visualization, interaction, and collaboration [28]. VR has proved its potential as a tool to enhance students' understanding of concepts and reduce misconceptions [29]. VR is an effective educational tool because it allows students the ability to interact with objects and space in real time compared to traditional distance, time, or safety constraints offered through traditional teaching [30]–[32]. Therefore, VR can be integrated seamlessly with online learning environments [33].

According to the Accreditation Board for Engineering and Technology (ABET) organization, the IE curriculum focuses on preparing "*graduates to design, develop, implement, and improve <u>integrated systems</u> that include people, materials, information, equipment, and energy. The curriculum must include in-depth instruction to accomplish the integration of systems using appropriate analytical, computational, and experimental practices*" (www.abet.org [34]). Hence, the IE discipline is focused on preparing students to understand integrated systems. With traditional teaching methods, the courses are taught in isolation. Systems concepts are complex,hence, students should understand well individual concepts as well as the big picture to be able to solve real-life problems [2]. With the current course-centric structure of the curriculum, students will not be able to see the connection between the topics, nor how they are related to real-life problems [2]. As a result, the connection between theory and practice is weak or even missing [35]. In light of this, the CLICK approach aims to create a clear connection between the courses in the IE curriculum. The objective of the CLICK approach goes beyond creating the connection between courses but also seeks to make a meaningful connection between knowledge and practice by providing hands-on experiences and real-life settings simulated in virtual environments.

The CLICK approach strongly aligns with the predicted changes in the classroom of the future in which VR, Augmented Reality (AR), and online learning have started to change and will definitely transform the educational landscape [18], [36]–[38]. The CLICK approach leverages VR to create immersive and real-life settings for systems (i.e., manufacturing and service) via teaching modules. These modules can be used in different courses across the IE curriculum to transfer and connect systems concepts. The authors hypothesize that the combination of VR and curriculum integration, i.e., the CLICK approach, will transform how the IE curriculum is delivered. The following section introduces the CLICK approach. The goals of this approach are to 1) provide the needed connection between courses, therefore improve students' learning and satisfaction, and 2) provide the needed linkage between theory and practice through a realistic representation of systems, therefore improve engineering identity and generate work-ready graduates. As a first step toward achieving these goals, a usability test is performed on one of the VR modules developed. The results from the test are analyzed with the objective of improving the design of the VR modules.

3. The CLICK Approach

To achieve the goals of curriculum integration, the authors are developing VR teaching modules for a manufacturing system to be used in the IE Department at Pennsylvania State University. However, the module could potentially be used by students and faculty from other universities. During the development phase, several outcomes will be measured and assessed by a group of students and faculty members. The assessments will include various aspects ranging from the efficacy of the VR module to the hardware devices selection. Figure 2 shows snapshots from the work-in-progress system. The following sections describe the framework of the CLICK approach.

Figure 2. Snapshots from the VR module.

3.1 Virtual System

To integrate the curriculum, a manufacturing system that produces power drills was chosen as the first teaching module to develop. Many considerations were taken in the selection of the manufacturing systems. For example, the system supports various challenges and can be used across many courses in the curriculum, is complex enough, and easy to implement. Power tools, such as power drills, have been used in previous studies that aim to integrate course knowledge [39]. Moreover, to develop the VR environment, the game engine Unity [40] was selected. Unity is extensively used by developers of serious game and educational games for its fidelity, accessibility, and community support [41], [42].

The first stage of the virtual system will simulate the initial steps of manufacturing a power drill. In these steps, the plastics housing of the drill will be manufactured (see Fig. 2). First, an injection molding press produces the housing components. Then an inspection station checks for any possible defective parts or parts that do not meet the quality standards. Finally, the plastic housings are packaged to be transported to the second assembly operation. In the finalized VR teaching module, students will be able to interact with the parts and machinery of the virtual systems.

3.2 Courses

The IE discipline is focused on preparing students to design, implement, and improve integrated systems that include people, materials, information, equipment, and energy [34]. The CLICK approach will have the same focus (i.e., systems concepts). To study curriculum integration, the authors selected four core courses from the IE curriculum at Pennsylvania State University that emphasize the concept of systems integration. These are (i) IE-322 Probabilistic Models in Industrial Engineering, (ii) IE-323 Statistical Methods in Industrial Engineering, (iii) IE-425 Stochastic Models in Operations Research, and (iv) IE-453 Simulation Modeling for Decision Support (see bulletins.psu.edu/university-course-descriptions/undergraduate/ie/). The approach can be expanded to include other courses in the curriculum, such as product design and measurement, human factors, engineering economics, and supply chain. Following the progression of the IE curriculum, the authors will focus first on integrating challenges, learning activities, and simulating real-world scenarios to connect and integrate the course knowledge from IE-322 and IE-323 courses. Below is a description of these courses and examples of what activities, topics, and concepts the virtual system will include and used across these courses. Subsequently, the other courses of the IE curriculum will be integrated.

IE-322 Probabilistic Models in Industrial Engineering & IE-323 Statistical Methods in Industrial Engineering

These are junior courses that are required for all the baccalaureate students in the IE department. IE-322 exposes students to probability theory and models and discrete and continuous probability distributions. The course also covers sampling distributions, point and interval estimation of mean, variance, and proportion. IE-323 exposes students to the statistical tools such as estimation, testing of hypotheses, control charts, process capability indexes, gage R & R studies, simple regression, and design of experiments. Both courses are necessary for solving and analyzing real-life engineering problems with uncertainty using data. IE-322 is a prerequisite for IE-323.

At this stage in the IE curriculum (i.e., IE-322 and IE-323 are junior courses), the students are not required to learn how systems work or how the components and parameters of the system interact. They are primarily observers and learn about data collection and analysis. In the virtual system, students can collect data such as waiting times when the demand (e.g., interarrival times) is changed, build distributions to this data, apply hypothesis testing methods, and make conclusions on how the change in the parameters (i.e., demand) influences the system's performance (waiting time). The students can use regression analysis to predict sales when changing the independent variables. The students could observe the effect of these variables within the virtual system and confirm their conclusions.

3.3 Journal

In addition to the virtual system, the integration is also facilitated by the use of a journal. Each student will keep a journal with him/her throughout his/her study to document all the activities and challenges related to the virtual system. The authors will convert this journal into a workbook in the future that will be distributed to the students in the first course of their junior year. The journal can serve as physical evidence that the student can use to keep track of all the activities, document the history, write notes, and revisit whenever needed. It is also a way to see the linkage between the courses [39].

3.4 Future Plan

The plan of this project is to assess the impact of i) using VR technology to teach IE concepts and ii) using VR teaching modules to integrate the IE curriculum. The assessment involves two cohorts: control and intervention groups. The authors are currently collecting data for the control group. Once the VR module is fully developed, relevant data will be collected and analyzed with respect to the control group. The assessment instruments involve self-report surveys and knowledge tests. Self-report surveys will measure attention, relevance, confidence, and satisfaction based on Keller's ARCS model [43]. Knowledge tests are created to involve the different levels from Bloom's taxonomy [44]. The data is collected for the courses listed in section 3.2. Other insights will be extracted from interviews with faculty and students. The following section describes the statistics of the current population. This information will be used to establish a baseline and to study the correlation between demographics and learning under the CLICK approach.

3.5 Target Population Statistics

A total of 24 IE students (58.3% males) from University X, who registered for *IE-322* (see section 3.2) during the fall 2018 semester, were selected as the first control cohort. These students completed a demographic and experience questionnaire, the Myers-Briggs type indicator questionnaire [45], the Engineering Identify questionnaire [46], and the Reduced Instructional Materials Motivation Scale (RIMMS) questionnaire [47]. In addition, students completed a knowledge test at the end of the course. The test covered the topics of: (i) discrete probability distributions, (ii) continue probability distributions, (iii) Poisson distribution, (iv) Normal distribution, (v) mean, (vi) standard deviation, and (vii) confidence intervals. The knowledge test was composed of 14 multiple choice questions. Following Blooms' taxonomy [44], two questions per concept were created, one that required lower order thinking skills (e.g., define, recall) and one that required higher order thinking skills (e.g., evaluate, analyze). Moreover, after 4 weeks (i.e., beginning of spring 2019 semester on the start of IE-323, see section 3.2), the same cohort of students re-took the knowledge test. Table 1 shows the summary statistics of the results from the questionnaires and knowledge tests.

The results of the paired t-test indicate that, on average, students' score on the initial test was not significantly different from their re-test score at an alpha level of 0.05 (p-value=0.139). Moreover, the results reveal that there was a statistically significant difference between their score on the lower order thinking skills questions and higher order skills questions for the initial test (p-value<0.001). However, this difference was not statistically significant for the re-test questions at an alpha level of 0.05 (p-value=0.073). Furthermore, when analyzing all possible covariates between the independent variables measured from the control group (e.g., items of RIMMS vs Items of Engineering identity, GPA vs Knowledge test scores), none were statistically significant at an alpha level of 0.05 after implementing a Bonferroni correction (i.e., 0.05/ $P_{(37,2)}$).

Table 1. Summary of control group statistics

	Freq.	*Proportion*		*M*	*Mds*	*SD*
Ethnicity			Age	21.7	21	1.1
Caucasian	15	0.63	GPA	3.1	2.9	0.4
Hispanic	3	0.13	RIMMS[1]			
Asian or Pacific Islander	3	0.13	Attention	13.15	13	1.49
Middle Easterner	2	0.08	Relevance	13.25	13.5	1.62
African American	1	0.04	Confidence	13.70	14	1.13
Program Level			Satisfaction	13.10	13	1.45
Junior	21	0.88	Overall=	53.20	54	4.29
Senior	3	0.13	Engineering Identity[2]			
Gaming Experience			Recognition	12.83	13	3.1
None	3	0.13	Interest	14.17	14	3.3
Some	11	0.46	Performance	21.38	24	4.8
Expert	9	0.38	Overall=	48.38	49	9.2
VR Experience			Initial Test[3]			
None	8	0.33	Lower order skills	4.31	4	1.36
Some	15	0.63	Higher order skills	2.96	3	1.29
Expert	0	0.00	Overall=	7.27	7	2.09
Big-5 Personality trait			Re-Test			
Extrovert	12	0.50	Lower order skills	4.35	5	1.54
Introvert	12	0.50	Higher order skills	3.58	4	1.12
Intuitive	17	0.71	Overall=	7.93	8	2.14
Sensitive	7	0.29				
Thinking	20	0.83				
Feeling	4	0.17				
Judging	17	0.71				
Perceiving	7	0.29				

[1] RIMMS questionnaire requires users to rate a set of 12 statements using a 5-point Likert scale. Each of the RIMMS items are based on the responses of 3 statements (i.e., max= 15). RIMMS is calculated based on the sum of all its items (i.e., max=60) [47].

[2] The Engineering Identify questionnaires require users to rate a set of 11 statements using a 6 point-Likert scale. The item of Recognition and Interest is calculated based on the responses of 3 different statements (i.e., max= 18), while the item of Performance is calculated based on the responses of 5 different statements (i.e., max= 30). Engineering Identify value is calculated based on the sum of all its items (i.e., max=66) [46].

[3] The knowledge tests were composed of 14 multiple choice questions (i.e., max points=14), 7 questions that required lower order thinking skills and 7 that required higher order thinking skills.

3.6 Virtual Reality Cost

VR technology is advancing very quickly, and the prices are going down with time. For example, Oculus has recently released a new headset called Oculus Go, and they are in the process of releasing a new headset, i.e., Oculus Quest. These headsets do not require a PC nor an attached wire. They are standalone VR headsets that are relatively powerful (compared to inexpensive VR headset options such as Samsung Gear) and align with the CLICK approach needs. The prices of these devices start at $200/unit and $400/unit for the Go and Quest, respectively. Headsets like this can be used in upper-level courses. For the lower-level classes, the students are more like observers at this stage. Low-cost devices such as Google Cardboard, Google Daydream, and Samsung Gear headsets can be used at this stage. These devices require a mobile phone to run. The prices of Google Cardboard and Daydream headsets are around $15/unit, and $99/unit, respectively. The price of Samsung Gear headset is around $130/unit [48].

Oculus Rift and HTC VIVE headsets require specialized computers with gaming capabilities (VR-ready). The price of VR-ready computer starts around $1,200/unit. Oculus Rift costs approximately $400/unit. HTC VIVE and HTC VIVE Pro cost around $500/unit, and $800/unit. Table 2 shows cost estimates for two class sizes – 40 and 100 students.

Table 2. Different scenarios of acquiring VR equipment [48]

Scenario	*Device(s)*	*Unit Price*	*Total Cost (40 students)*	*Total Cost (100 students)*
1 – preferred for upper level classes	Oculus Go	$200	$8,000	$20,000
2* – preferred for lower level classes	Google Cardboard	$15	$600	$1,500
3	Oculus Quest	$400	$16,000	$40,000
4	Google Daydream	$99	$3,960	$9,900
5*+	Samsung Gear	$130	$5,200	$13,000
6	Oculus Rift with PC	$400 + $1,200	$64,000	$160,000
7	HTC VIVE with PC	$500 + $1,200	$68,000	$170,000
8	HTC VIVE Pro with PC	$800 + $1,200	$80,000	$200,000

* These devices require mobile phones to run
+ Samsung Gear runs with Samsung mobile phones only

4. Usability Test

Usability testing has become an essential part of the software and engineering design process [49], [50] since system's usability is an important feature that correlates to the quality of user experience [51]. Hence, in this work, an initial usability test is performed on one of the VR modules developed for the CLICK approach. The module described in section 3.1 and illustrated in Figure 1 was used for this test.

4.1 Participants

In recent years, crowdsourcing methods have emerged as a new paradigm for usability evaluation in the software development process [52], [53]. Crowdsourcing methods are a cost-effective way to test the usability of a system which takes advantage of crowds. In this work, participants for the usability test were recruited via the crowdsourcing platform Amazon Mechanical Turk (AMT). AMT is a popular platform that designers and engineers are employing during their software development process [54]. Crowdsourcing platforms, such as AMT, are valuable tools for developers since researchers have found that the response consistency between internet users and laboratory participants are no significant differences [55], [56]. Moreover, AMT provides the benefits of (i) low cost, (ii) large participants pool access, and (iii) large participants pool diversity [55].

Since the VR module tested was a simulated manufacturing line, participants that were identified by AMT as engineers working in manufacturing organization were selected for the usability test. All the participants were compensated $2 for their time and were offered a bonus of up to $3, based on the amount of relevant information provided in the open-ended questions. Only raters with a 95% satisfaction rate or greater were allowed to participate. Other quality assurances were set in place, which are explained in the next section.

4.2 Virtual Environment and Questionnaires

After providing consent, the participants were given detailed instructions of the usability test, virtual environment, and questionnaires presented. For this test, the virtual environment described in section 3.1 was employed. Participants were able to interact with the virtual environment via a 360-degree video (youtu.be/6aFhz0yQrvE). The virtual environment was composed of an injection molding press that makes plastic housings of power drills, a conveyor that allows plastic housings to cool down, and a robot arm that picks the housings from the conveyor and places them in a tote. Participants were informed of the objectives of the virtual environments to teach engineering students concepts relating to queueing theory, probability distributions, and manufacturing systems design.

After interacting with the virtual environment, participants were asked to complete the Systems Usability Scale (SUS) questionnaire [57], [58]. SUS required the participants to rate how strongly they agree or disagree with 10 statements using a 5-point Likert scale (1: strongly disagree, 5: strongly agree). For this questionnaire, participants were instructed to record their immediate response to each item, rather than thinking about it for a long time. If they were uncertain regarding a particular item, they were instructed to mark the center point of the scale (i.e., 3).

After the SUS questionnaires, participants were presented with three open-ended questions. In these questions, they were asked to provide feedback about what they liked and disliked the most about the system, and what they thought would be the best way to navigate the virtual environment. Finally, participants completed a demographic and experience questionnaire. In these questionnaires, they were asked about their gender identity, age, educational level, occupation, and years of experience. Moreover, using 7-point Likert scale (1: not experienced, 7: very experienced), they were asked to rate their experience with Manufacturing Systems, Assembly Lines, Queuing Theory, Virtual Reality, and 360-Degree Videos. In these questionnaires, a quality control question was also implemented to ensure participants were not just randomly clicking through the survey.

4.3 Results and Discussions

After filtering out participants that did not pass the quality control question and spent less than 10 seconds reading the instructions page, the data of 14 participants (2 females) was analyzed in this work. All participants described themselves as engineers, from manufacturing engineers (70%) to mechanical engineers and product development engineers (30%). Participants took on average 9.88 minutes to complete the usability test (SD=3.2) and spent 1.98 minutes interacting with the virtual environment (SD=1.1). Table 3 shows the summary statistics for the participants' responses to the demographics and experience questionnaires.

Table 3. Summary of demographic and experience questionnaire

	Freq.	*Proportion*		*M*	*Mdn*	*SD*
Highest degree achieved:			Age	32.86	30	7.92
Associate Degree	2	0.14	Years of experience	8.57	6.5	7.64
Bachelor's degree	9	0.64	*Experience with:*			
Master's degree	3	0.21	Manufacturing Systems	6.14	6	0.66
			Assembly Lines	6.21	6	0.75
			Queuing Theory	3.64	4	1.69
			VR Systems	4.29	4	1.68
			360-Degree Videos	5.00	5	1.30

The results of the SUS reveal that, on average, participants reported the system having a usability score of 61.3 (SD=14.4, Max=85, Min=43). The result indicates that the system has some potential to be used as a teaching module, but some work needs to be done in order to improve its overall usability. Moreover, the range of values and the variation on the results indicate that there is not a lot of agreement between participants regarding the usability of the system tested. In order to understand if participants' usability responses were correlated to their background (i.e., demographics and experience), a linear regression model was fitted using participants' standardized SUS score as the dependent variable. For the independent variables, a stepwise backward propagation variable selections method using Akaike Information Criterion (AIC) was implemented [59]. In this procedure, no interaction terms were evaluated. The model with all variables (i.e., *Gender, Age, Highest degree achieved, Years of experience, Exp. with Manufacturing Systems, Exp. with Assembly Lines, Exp. with Queuing Theory, Exp. VR Systems, Exp. with 360-Degree Videos*) showed an AIC of 0.86, while the model shown in Table 4 had the best AIC of the models tested (AIC= -7.86). The results indicate that this model was statistically significant ($F_{4,9}$ = 5.232. p-value=0.019) with a R^2 of 0.70. Table 4 shows the summary statistics of the model fitted and the independent variables selected. The results reveal that participants who have more experience in manufacturing systems, virtual reality, and had more years of professional experience tended to report higher usability scores; while participants with more experience with 360-degree videos reported lower usability scores.

Table 4. Summary of linear regression fitted

Variables	*Standardized β*	*Std. Error*	*t-value*	*p-value*
Intercept	-6.52	1.87	-3.49	0.007**
Exp. Manufacturing Systems	1.06	0.32	3.24	0.01*
Exp. VR Systems	0.47	0.16	3.03	0.014*
Exp. 360-Degree Videos	-0.52	0.2	-2.58	0.029*
Years of professional Exp.	0.07	0.03	2.53	0.032*

Note: Significance level codes (*p-values*): <0.01**,<0.05*, <0.1’

Furthermore, the open-ended questions reveal that the most frequently used words when answering the questions “*What you liked the most about the system?*” were “easy” (freq. 6) and “system” (freq. 4). In addition, the semantic network analysis [60] indicates that the most frequently used words bigrams were (i) automatic→system, (ii) feel→realistic, (iii) safe→environment, (iv)immediately→ visible, and (v)low→cost. In contrast, for the questions of “*What you disliked the most about the system?*” the most frequently used words were “video” (freq. 4) and “system” (freq. 4), while the most frequently used words bigrams were (i)object→moving, (ii) robot→arm, (iii)360→viewing, (iv) individual→elements, and (v)injection→ machine. The open-ended questions reveal that while they found the system easy and safe to use, realistic, and a low-cost option, they did not like the 360-degree video itself. Some participants complained about the low resolution of the video. With regard to the virtual environment, participants suggested that the way the plastics housing move in the conveyor and the movement of the robot-arm could be improved. Moreover, they indicated that adding some animation to the injection molding machine, some sound effects, and more object and machinery in the background could improve the virtual environment.

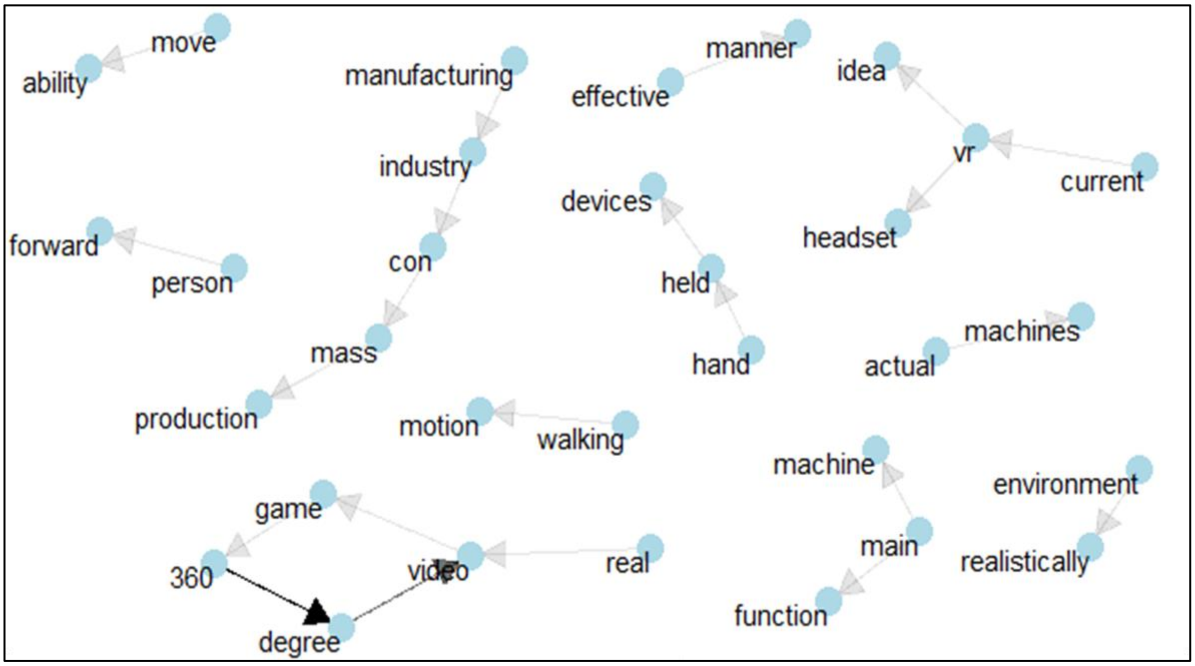

Figure 3. Semantic network *(color intensity if arrows indicate the frequency of bigrams)*

When analyzing participants' responses to what they thought would be the best way to navigate the virtual environment, the most frequently used words were "video" (freq. 6) and "move" (freq. 4). Figure 3 shows the semantic network constructed from the participants' responses. The word bigrams most frequently used were (i) 360→degree, (ii) degree→video, (iii) actual→machines, (iv) move→ability, and (v) walking→ motion. The results reveal that participants consider having the capability to view the virtual environment in a 360-degree using a VR headset as a good idea. However, they also indicated that allowing the user to move or walk around the environment would be beneficial. This can be done with the use of controllers that allows the user to change their viewing position in the VR environment, and take a closer look at the virtual machines and elements. This will resemble more how industrial engineers are capable of walking in real manufacturing environments.

5. Conclusions and Future Works

This work presents the current shortcomings in engineering curricula focusing on the IE curriculum. The shortcomings stem from the rigid course-centric curriculum structure in which courses are taught in silos by usually independent faculty. Thus, resulting in a lack of connection between the concepts taught in different courses and lack of relevance of these concepts to real-life settings. These shortcomings are concerning in higher education. The authors developed a new approach that leverages VR technology to integrate the courses across the IE curriculum. The approach is called Connected Learning and Integrated Course Knowledge (CLICK). This work introduces the CLICK approach and explains how it would be implemented and assessed. In addition, the authors presented a preliminary study for the usability of one of the VR modules that are being developed and described the target student population for this approach.

The usability study indicated that the VR module presented is a good start, but there still some areas for improvement. This was expected by the authors since the module still is in the development phases. Nonetheless, the results provided the authors a clear path to continue improving the VR module and provided a better understanding of what users perceived as usable in virtual environments that simulated manufacturing lines, similar to the one presented in this work.

Future work will involve assessing the impact of the CLICK approach on students' learning, motivation, and preparation to be successful engineers. The results of this study will inform us on how to implement this approach on a large-scale. More VR teaching modules will be built and shared with the community. It is expected that the approach will be adopted by other institutions to widen the broader impact of this project.

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