Development of Industry 4.0 Virtual Lab for Manufacturing Engineering Education

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Abstract

A technology driven society of 21st century demands skilled technocrats and engineers. To fulfil this demand, a revolutionary transformation is required within higher education. With time, the traditional classroom teaching is being replaced by ultra-modern techniques, textbooks by e-books and online database, student backpacks by smart electronic devices, and physical labs by virtual labs. E-learning has been introduced for convenient quicker learning and better understanding. The virtual lab is an interactive tool in higher education that contributes to dynamically prepare the engineers ready for the 4th industrial revolution. This tool is capable to address the need of practical component in engineering education in case of unavailability of sophisticated expensive machines and highly skilled lab technicians. The virtual laboratory sessions mimic reality and create learning experience similar to physical laboratory sessions with flexibility. At University of Johannesburg, an Industry 4.0 Virtual Lab has been developed for manufacturing engineering education. This article discusses the rationale and philosophy behind and various important aspects as regards to the development of virtual lab sessions for manufacturing engineering education of the undergraduate level students at University of Johannesburg.

Keywords
Education, Engineering, Industry 4.0, Manufacturing, Virtual lab

1. Introduction

The Fourth Industrial Revolution (4IR) has embedded a global wave in Industry. Industrial changes and upskilling the workforce in Africa is a challenge that needs immediate attention. South African school curricula have embedded Technology as a learning area and Industry adapts at a very fast pace to immediate skills requirements. The question remains however on how equipped higher education is for skilling engineering students to make the leap from a basic school education in technology to become a fully-fledged global citizen and engineering practitioner in South Africa (Senne, 2018; Educause, 2018). Moreover, the general use of technology for teaching and learning is also a meme brought over for many years as students of technology learn by using technology. Therefore, a teaching initiative has emerged for teaching basic concepts of Mechanical Engineering to students who use technology as a general means for discovery learning. This paper largely addresses the design thinking and development of a Virtual Engineering Laboratory, designed, piloted, and tested to stay abreast with concepts needed to understand to become engineering practitioners.

A group of Mechanical Engineering students at the University of Johannesburg were used in the pilot phase of this project. A questionnaire related to the concepts of needed engineering skills was provided as well as a qualitative section aimed at the learning experience, recommendations, and critique by the end users (engineering students). At this comprehensive university with four campuses, two campuses involved in Engineering, were used with a heterogeneous group of 17 students as focus group.

The paper starts by conceptually explaining how Instant Gratification, Gamification, Mental Modelling, Activity Theory, Gamification, and Instant Gratification significantly aids the design thinking process to describe the design and development of the Virtual Engineering Laboratory. Thereafter, the qualitative responses given by students who have tested and explored the Virtual Laboratory, will be analysed and categorized to reveal their learning experience(s) to contribute to the efficacy and affordances for using such an initiative in their teaching and learning programme. Recommendations for further development are provided as a continuation for further development and implementation throughout the paper.

2. The Virtual Lab As a Concept

Technoculture as phenomenon of modern society brought about news ways in which students work, think, and learn (Educause, 2018; Brock, 2016). Even more so, the engineering Industry is based on an experimental reality staying a courante with the latest developments and technologies informing the progress of human development. In the same instance, the training of modern engineers also demands new teaching methods, innovation and new pedagogy to resonate with the challenges of Industry and behaviour of modern students. Moreover, limited space (such as practical experience in a laboratory), the time needed to master skills and skills applications, as well as being Industry-ready, have become exceptionally demanding – so does the quality of training needed to accommodate fast adaptation in Industry 4.0. The inevitable adoption of these technologies filters into the general population at a fast rate to such an extent that new engineering developments place engineering practitioners facing challenges of also being innovators and inventors (creators) at the same time in a 21st century knowledge economy (Educause, 2018; Kiersz & Gillet, 2017). We therefore argue that engineering students should be brought to a level of problem solving beyond the basic theoretic requirements so they can start creating and inventing better feasible and sustainable solutions. Consequently, more self-regulated tasks need to be built into curricula and training programmes to accommodate the development of complex cognitive skills (Kiersz & Gillet, 2017). The task of preparing and developing younger engineers now resides with teachers of technology in secondary schools and engineering lecturers in higher education institutions. We hope that the development of this Virtual Lab contributes to such innovative ways of teaching and learning in the field.

The teaching innovation scheme at University of Johannesburg promotes such projects where the traditional classroom teaching is being replaced by ultra-modern techniques, student backpacks by smart electronic devices, and physical labs by virtual labs. The interventions of information and communication technologies and E-learning concept have been encouraged for convenient quicker learning and better understanding. It is worth mentioning that the university is sponsoring the cost of such projects. The industry 4.0 manufacturing engineering virtual lab has been one of such selected projects. The rationale behind the virtual lab for manufacturing engineering education is as given below.

Globally, the Industry 4.0 concept is in trend and being given considerable importance to stay competitive. To overcome the challenges and success of industry 4.0 transformation, it is necessary to provide the knowledge of the required technologies at higher education level where future manufacturing/industrial/mechanical engineers are built. It is the biggest factors behind conceptualizing the virtual lab. It was intended to develop virtual lab sessions consist of a sophisticated learning management system that contains basic theory and mechanism, graphics, animations and/or videos, and self-evaluation tools for better understanding and learning of the students at their own pace and convenience.

3. Methodological Research Approach

Following the rationale, we decided to use the Design Experiment methodology. This methodology is also known as Design-Based-Research (DBR). Design-Based-Research is: “The design-based research paradigm, one that advances design, research and practice concurrently, has demonstrated considerable potential.” The same authors extrapolate that: “design-based research posits synergistic relationships among researching, designing, and engineering.” And add that: “Design experiments manifest both scientific and educational values through the active involvement of researchers in learning and teaching procedures and through "scientific processes of discovery, exploration, confirmation, and dissemination” (Wang & Hannifen, 2005). In our development, a small heterogeneous group of Mechanical Engineering Manufacturing students have been used. This group is the whole class. In this case, because of the iterative nature of DBR, a questionnaire was used on this pilot group. After design between the lecturer (subject matter expert) and an e-learning specialist, the design and development took place over eight months with regular interventions. Notes were kept digitally and the design process went through several interventions. Each evaluation process delivered valuable data. However, the purpose of this paper is not only on the developmental process of the Virtual Lab but also focusses more on the learning experience we assumed to have been created for the students who will be the end users. The qualitative data gathered from the questionnaire responses (90%) will be used together with the notes and digital artefacts created throughout the process thus far. We therefore structure this presentation with the focus on learning experience design of a Virtual Lab for Manufacturing Engineering students and their experience thereof.

4. Virual Lab Design Considerations

Finding information fast is the way students learn. Contradicting traditional chalk-and-talk or merely demonstrating a concept does not fulfil all the steps in the learning process anymore (Educause, 2018; Education.co.za, 2018). Especially engineering students tend to be inquisitive requiring more prior knowledge for understanding current fundamental concepts. One does not have to look far to see how modern students seek instant gratification of knowledge by merely acknowledging the Internet as the first and foremost provider of instant information to instantaneously satisfy immediate inquiry. Some researchers are of meaning that this form of instant gratification is a consequence of learning how ‘new’ games work and how to play these games, continuously exploring apps, and applying features added to evolving smart phones, all throughout adolescent years. We support theory on this by researchers such as (Gautam, et al., 2018; Harasim, 2012) who inter alia state that: “As technologies continue to develop and evolve, it is imperative that instructional technologists, learning scientists, and educators involved with examining learning affordances of emerging technologies investigate the potential of innovative environments to promote and facilitate learning.”

Figure 1: Screen concept of industry 4.0 virtual lab

Complementing instant gratification is an intuitive user interface and self-explanatory icons. This look-and-feel must as much be behaviouristically accepted by the mind of the student as to complement the construction of knowledge. Figure 1 reveals the concepts mentioned in this section, whereas Figure 2 shows the same concepts within the micro-learning focused on a specific set of tasks for students. The reader should also consider that these learning concepts are pivoted by the following learning outcomes:

4.1. Overall Outcomes

Upon successful completion of the designed lab sessions, the students should be able to:

- Outline the features and working principles of manufacturing processes for making mechanical products.
- Select manufacturing processes for producing a designed mechanical product.
- Identify different products that are made through various manufacturing processes.
- Perform manufacturing operations on the machines and setups.

4.2. Outcomes for Experiment 1

The students should be able to:

- Explain what sheet metalwork entails.
- Understand the mechanism and working principle of various sheet metal cutting and forming processes.
- Differentiate between the various sheet metal forming processes and techniques.
- Identify the different components that are manufactured through various sheet metal processes.

4.3. Outcomes for Experiment 2

The students should be able to:

- Identify various machining processes.
- Explain the mechanism of metal cutting.
- Understand the mechanism and working principle of turning process.
- Understand the machines and tools required in turning process.

4.4. Outcomes for Experiment 3

The students should be able to:

- Differentiate various bulk deformation processes.
- Identify the parts made by bulk deformation processes.
- Understand and explain the working principle of rolling, forging, and extrusion processes.

It is planned to add two more experiments for the next iteration.

We stated earlier that the quality of delivery of teaching and learning material is a relevant issue. The way in which this quality is delivered to aspirant engineers, is by means of Mental Modelling. The term Mental Modelling is described in (Interaction Design Foundation, 2018) as: "procedure of making users to hold a belief about any system or interaction". These beliefs resemble real life models. Based on the mental model i.e. the beliefs, the users plan and predict future actions. Therefore, to ensure the same quality and stance of thinking, the ethos of an engineering practitioner, the way-of-doing of an engineer as well as incorporating the 'learning-to-be' philosophy of teaching and learning of the University of Johannesburg, the Virtual Lab has been designed to equip students with 'engineering' working ethics.

A deeper learning ethos is to avoid students from bluntly studying concepts from any platform on the Internet but rather to abide by trustworthy, academic resources and digital media. Thus, digital artefacts were created authentically for the type of engineering students following the current programme. Furthermore, not to neglect the leadership development of students, design thinking (as a process) was embedded in the way the experiments in the Industry 4.0 Virtual Lab were presented. This process was followed by implicitly guiding the learning process as to be that of a project manager to bring the experiments as relevant as possible to industrial practices.

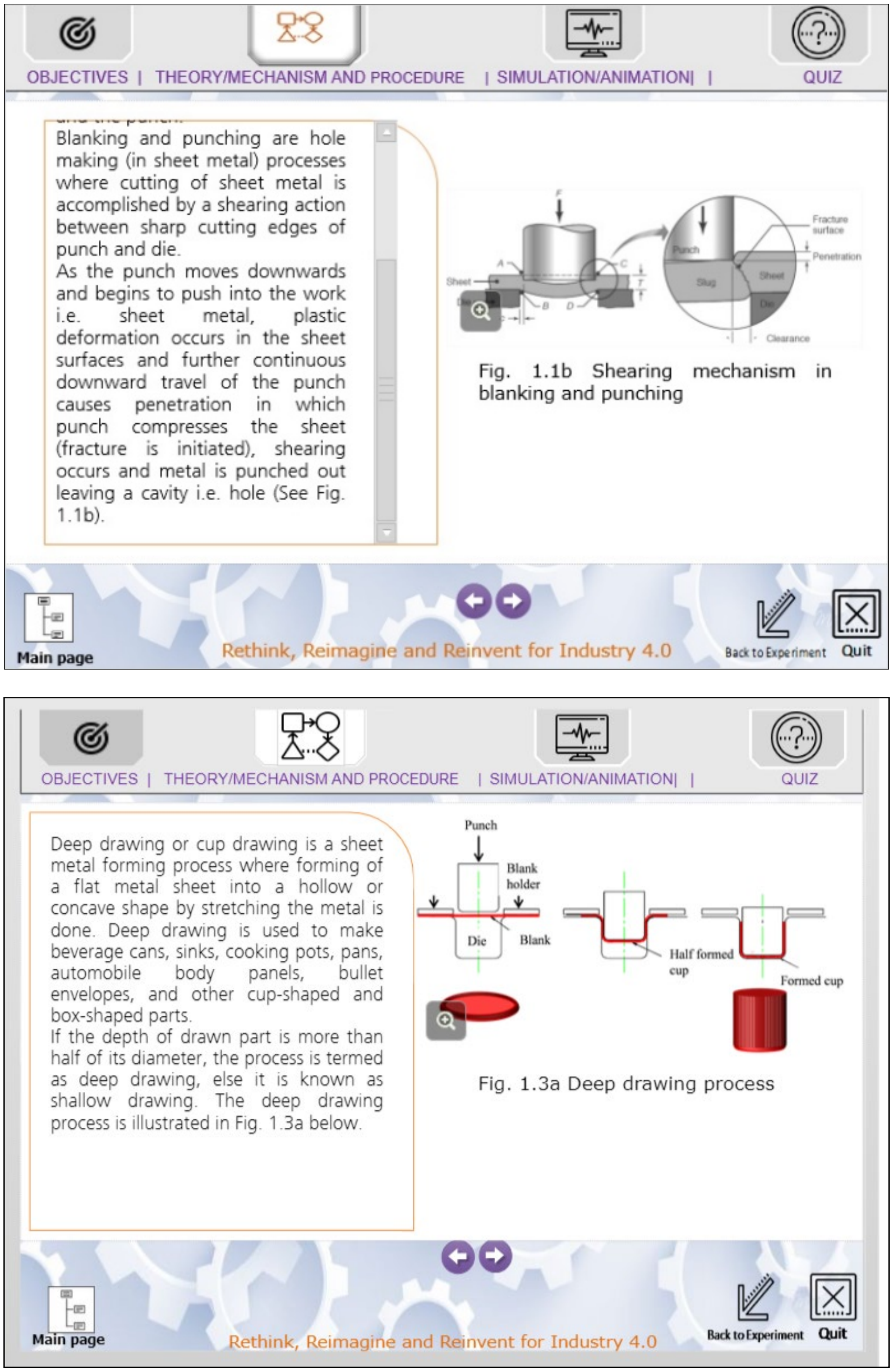


Figure 2: Micro-learning concepts in industry 4.0 virtual lab

Presenting information to students in such a way that they make meaning of existing information to construct ‘new’ knowledge falls under the concept of constructivism. In constructivism, the learner is the active creator of his/her own knowledge (Interaction Design Foundation, 2018; Learning-Theories.com, 2018). Learner constructs his/her own understanding through experiences and reflection on those. Taking in regard that modern students learn by doing by receiving smaller units of learning to assimilate understanding, is coined as *Micro-learning* (Interaction Design Foundation, 2018). Micro-learning is thus defined as: "a type of training delivered in small units. They're designed to help learners tackle a large volume of learning content by taking small chunks at a time. A micro-learning course can be just a five or 10 minute lesson, or a series of short standalone lessons that are targeted on just one certain learning objective" (iSpringsolutions.com, 2018). The needed information to construct new knowledge from existing knowledge is used in the design concept for guiding students to investigate the relevant experiments proposed with Industry 4.0 Virtual Lab.

5. Brief Content Description

In industry 4.0 virtual lab, at this pilot phase, three experiments/labs have been developed. The idea behind selection of these experiments was to facilitation the study of the currently enrolled students for manufacturing engineering subject. The objectives of all three experiments are as follows- to study sheet metal processes, to reduce the workpiece diameter by turning, and to study various bulk deformation processes. All are basic manufacturing processes whose knowledge is a prime requirement to be given in a mechanical engineering undergraduate study. Important definitions, fundamental aspects, machine features, working principle, salient features, and applications of all the respective manufacturing processes are provided through various tools of the learning management system of industry 4.0 virtual lab.

Within a South African context, the Industry 4.0 Virtual Lab aimed at giving the students an overall, guided learning experience. As with any learning programme, these students still needed to be guided by designed learning experiences within a digital environment. This learning ecology was integrated within existing university infrastructure to ensure proper access for each student. Dissemination of the Industry 4.0 Virtual Lab was done as an integration within the existing learning management system (LMS), Blackboard. Because of the mobile abilities of the LMS, the Virtual Lab is also accessible across mobile device platforms via smartphones and tablets. An integrated WiFi network ensures access on the four campuses as well as real time interaction among students an students as well as lecturers within a secure system. Furthermore, the Industry 4.0 Virtual Lab was created as a SCORM (Sharable Content Object Reference Model) package which provides for full student tracking capabilities. This allows for data to be captured about the use of the system for future developments. The Industry 4.0 Virtual Lab provides a proper quiz after each content "chunk" and record is kept within the LMS. The quiz can be revisited and provides feedback and reviews. This allows for continuous assessment for student monitoring as well as for self-assessment opportunities for students (Blackboard.com, 2018). Figure 3 presents the snapshot of quizzes put on virtual lab learning management system.

Here it is essential to mention the most important tool of the interactive learning management system of industry 4.0 virtual lab, that is, 'animations and videos'. Following the *Cognitive Learning* theory (Hergenhahn & Olson, 2005) with an aim to enable the students to conect with and visualize the topic and contents much better than traditional practice, the indegneously developed animaions and videos of the manufacturing processes falling under all experiments have been included. The sequence of steps, important parts and working principle of various manufacturing processes are shown. It provides more relistic experience and ensures better understanding and thereby enhanced learning. Figure 4 presents snapshots of some of the animations and a video used in industry 4.0 virtual lab.

The qualitative and quantaive evaluation of the feedback of the students indicate the effectiveness of the learning management system of virtual. The next section provides insights on some of the aspects of the student's feedback.

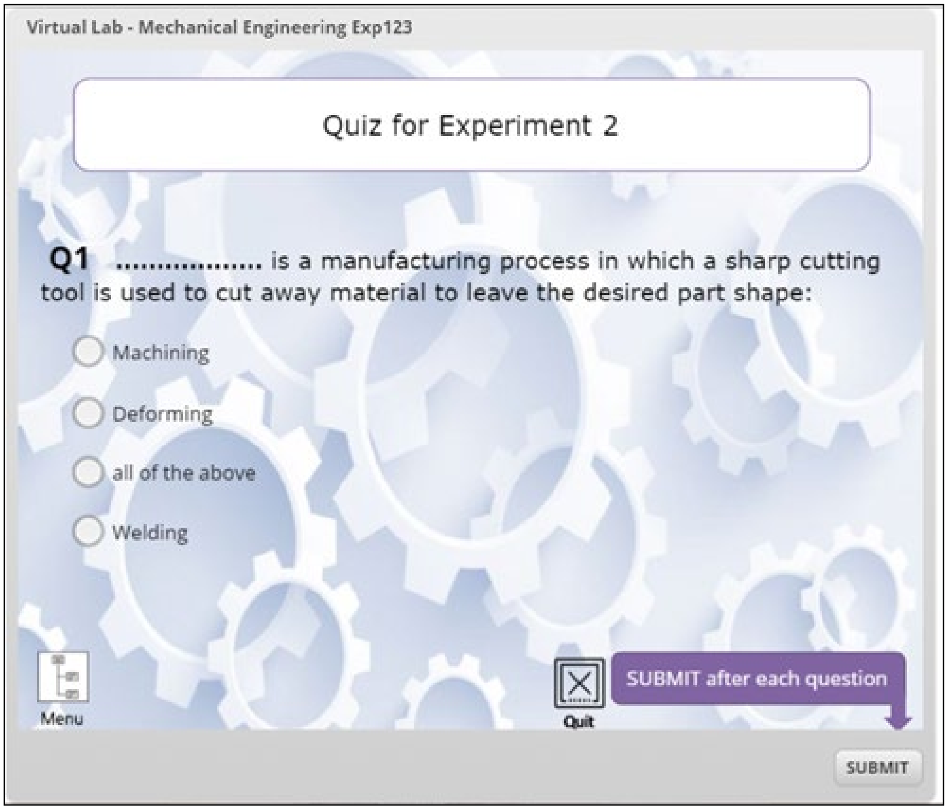
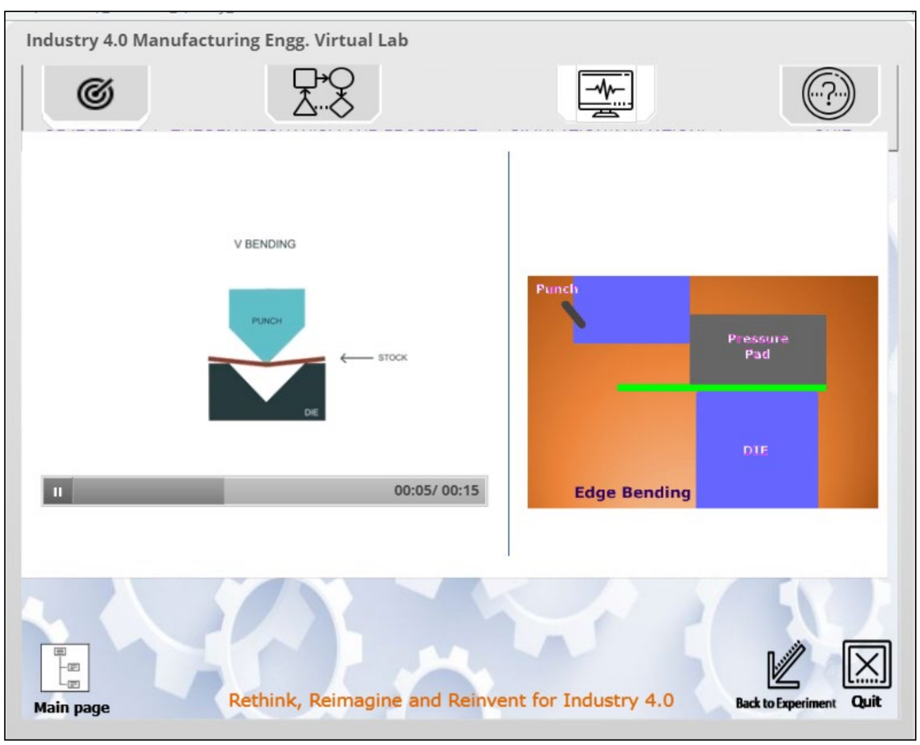


Figure 3: Format of student quiz in industry 4.0 virtual lab



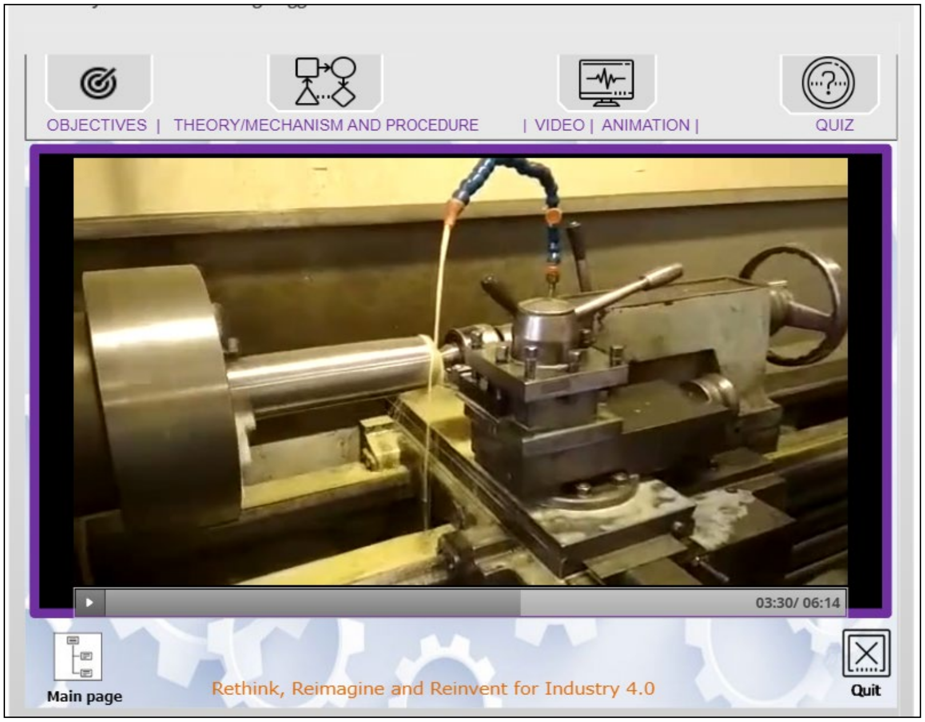


Figure 4: Animations and video in industry 4.0 virtual lab

6. Data Informed Iterations

The responses reveal a general positive attitude and acceptance of the Industry 4.0 Virtual Lab. Because of the scope of this paper and space limit, only the following summary as regards to the feedback of the learners is given:

Overall ratings were given on seven categories by using a Likert scale, being:

1 – Not Applicable

2 – Strongly Disagree

3 – Disagree

4 – Agree

5 – Strongly Agree

A set of 20 questions constructed from the questions mentioned in this paper, circumscribe seven categories, namely:

i. Look and feel (appearance);
ii. Accessibility;
iii. Ease of navigation;
iv. Content provided;
v. Digital artefacts (video, animation, interactive activity);
vi. Assessment in the form of quizzes, and
vii. Self-assessment opportunities such as reflection.

The categories and application thereof were all rated 4 and 5 in the responses.

Related to comments provided by the respondents (i.e. manufacturing engineering students to whom the virtual lab access was given), the comments can be divided into two main categories. These categories as well as examples from the anonymous respondents are given below in Table 1.

Table 1: Feedback comments of the students on industry 4.0 virtual lab

	Categories	
	Learning efficacy	**Recommendations**
Excerpt responses	*"Industry Virtual Lab is a great approach in enhancing the future of Education and can help a lot in developing skills not just at school, but also in the practical world"*	*"All Virtual Labs were done to improve our knowledge, am [I am] in support of virtual labs to be done in future for coming students"*
	"The virtual lab helped me to see the processes that I am taught in action, which is now easier to remember as I study"	*"Please advise the other lecturers to introduce virtual lab as well"*

6. Conclusions

The following preliminary conclusions related to the Industry 4.0 Virtual Lab for Engineering student, can thus far be stipulated as:

- The mental modelling process was clearly motivated by the design thinking process.
- A variety of digital artefacts-related to how the general digital information is provided on the Internet and in digital spaces is to the liking of students who use modern learning ecologies.

This development was tested on the qualitative responses of the students in a pilot study. The quantitative data will be used to address other experiential issues related to the teaching and learning experience to be published and presented in follow-up research.

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Biographies

Kapil Gupta is working as Associate Professor in the Dept. of Mechanical and Industrial Engineering Technology at the University of Johannesburg. He obtained Ph.D. in mechanical engineering with specialization in Advanced Manufacturing from Indian Institute of Technology Indore, India in 2014. Advanced machining processes, sustainable manufacturing, green machining, precision engineering and gear technology are the areas of his interest. Several SCI Journal and International Conference articles have been credited into his account. He has also published some books on hybrid machining, advanced gear manufacturing, micro and precision manufacturing etc. with renowned international publishers.

Arno Louw, is a Senior Specialist in Instructional Design at Center for Academic Technologies, University of Johannesburg. He is specialized in engineering education 4.0, e-learning, virtual reality based education, gamification, and game-based learning. Arno has delivered several invited and keynote speeches in the international symposiums, conferences, and workshops on teaching and learning. Arno has published many papers in international conference proceedings and journals. He is extensively involved in training lecturers and staff on using learning management system and operating university's educational portal (blackboard). He is busy doing many local and international projects on Industry 4.0 based higher education.

Madindwa Mashinini is a Senior Lecturer in the Dept. of Mechanical and Industrial Engineering Technology at the University of Johannesburg. He holds a post of head of the department currently. He obtained PhD in welding technology and conducting research in advanced manufacturing. He has published many papers in international journals and conference proceedings of repute. He is supervising postgraduate students in mechanical engineering. Madindwa is a member of many professional societies and serving as a member of advisory committees of conferences. He is also busy doing research projects and publications in teaching and learning.

Doctor Mukhawana is a Lecturer in the Dept. of Mechanical and Industrial Engineering Technology at the University of Johannesburg. He holds a Master degree with specialization in manufacturing engineering. Doctor is a member of various committees of research and teaching and learning. He is pursuing PhD in manufacturing engineering. He has published many conference articles. Doctor is doing research projects in manufacturing engineering and teaching and learning. Project-based learning, virtual reality-based education, game-based education, and engineering education 4.0 are the areas of his interest. He is busy implementing innovative techniques for the improved teaching and enhanced learning of the students. Recently, he has developed a virtual lab for manufacturing engineering students.