Evaluation and Analysis of Students Feedback on Industry 4.0 Virtual Lab developed for Manufacturing Engineering Education

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Abstract
The University of Johannesburg is promoting decolonization of knowledge and Industry 4.0 based higher education interventions to prepare locally relevant and internationally competitive students. As regards to that, a project sponsored by teaching innovation fund, and based on development of virtual lab for manufacturing engineering education has been done. This paper reports an analysis of the feedback of students who explored the Industry 4.0 virtual lab developed for manufacturing engineering education. A feedback questionnaire with a total of twenty questions on virtual lab learning management system and its effectiveness was developed and distributed to the students for anonymous feedback. It is found from the analysis of the feedback that 90% of the students were agreed with the quality and effectiveness of the developed virtual lab. Some of the recommendations and qualitative feedback of the students were found very useful for further development of virtual labs.

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

1. Introduction
Highly skilled technocrats and engineers having knowledge of information and communication technologies along with their parent fields are in great demand in this era of the 4th industrial revolution. To fulfil this, a revolutionary transformation is required to be done at large within engineering education. In-fact, that transformation has been started with the intervention of information and communication technologies in education. It is in the form of replacements of traditional lecturer’s chalk board and student’s backpacks by ultramodern e-learning classrooms and smart devices like tables etc. respectively. Students or learners are being facilitated to explore and understand the course contents, submit assignments, and write assessments 24 by 7 being stayed remotely and at their own pace and convenience.

The 4th industrial revolution i.e. Industry 4.0 concepts are being taken place in all sections of manufacturing industry across the globe. It is a current trend of automation and data exchange in manufacturing technologies and majorly includes cyber-physical systems, the internet of things, cloud computing and cognitive computing. With regards to that, virtual manufacturing is identified as a tool for efficient working of the future factories (Lan 2009; Souza et al., 2006). On the other hand, problem and project based learning, CDIO, and game based education have their unique importance (Gupta et al., 2019).

To build industry 4.0 ready engineers, it is imperative to train and engage them in the activities as regards to their engineering education and in-fact respective modules where they can gain knowledge and apply that to build competency. The virtual laboratory is an interactive learning tool which can replace the physical laboratories in case where there is limited access to the machines and equipment; students registered late or missed the labs; and unavailability of the skilled technicians. The virtual laboratory sessions mimic reality and create learning experience
similar to physical laboratory sessions with flexibility (Ari-Gur et al., 2015). Some literature based on past work on virtual lab development has been reviewed by the author and discussed here as under. Richards et al. (2015) developed virtual lab for fluid mechanics education. The lab was so user-friendly in the sense that learners could be able to control the functioning of the instruments and conduct experiments being located remotely. A survey was also conducted by them where appropriate feedback was given by the learners for further improvement. For microstructure evaluation of various engineering materials, a material science virtual laboratory was developed successfully by (Dobrzanski and Honysz, 2007). In an important work, students appreciated the tablet manufacturing virtual lab and found very effective to understand concepts in pharmacy education (Mattsson et al., 2016). A recent paper by Grodotzki et al., 2018 describes in detail about the extensive work on development of virtual labs for engineering education by German universities. Under ‘Excellent Teaching and Learning in Engineering Science’ project, various types of remote laboratories and virtual learning environments were developed such as tele-operative testing cell for material science, tube bending cell, virtual testing cells, and universal virtual experimentation lab. 2D and 3D animations and short videos were majorly focused in the development. However, for education of manufacturing engineering subjects, still more work is required to be done on the development of virtual labs. With an aim to fulfill the gaps on education requirements and to build industry 4.0 ready engineers, manufacturing engineering virtual lab has been developed at University of Johannesburg. The main aim of the industry 4.0 manufacturing engineering virtual lab was to provide remote access to the laboratory environment of various manufacturing processes for practical purposes. The comprehensive learning management system equipped with theoretical details, data-sets, videos, animations, and quizzes gives the users i.e. students the feel of actual laboratory. The following were the intended outcomes of the virtual lab project:

- Enhanced learning and in-depth understanding of the manufacturing subjects linked.
- Increased interest, practical training and development towards scare/critical skill area ‘advanced manufacturing’.
- Competency building towards achieving graduate attributes.
- Contribution to the student engagement period to confirm the course credit level.
- Understanding of Industry 4.0 concept and professional development of the students.

This paper presents the design of virtual lab developed for manufacturing engineering education, discusses the evaluation and assessment of the developed lab by students, and concludes with some future recommendations.

2. Design

Manufacturing engineering is a compulsory module required for National Diploma and BEngTech professional qualifications in mechanical engineering at University of Johannesburg. One of the expected learning outcomes of the module is to understand and explain the working principle and mechanisms of various important manufacturing processes. To facilitate this, virtual lab has been developed to illustrate three major manufacturing process categories for better understanding and enhanced learning of the students. A friendly graphic user interface consists of various tabs prompting to theory, animation/video, and quiz was created to explain various manufacturing processes via virtual lab learning management system. Figure 1 illustrates the displays of various pages of virtual lab showing important features where introduction, salient features, theory, animation, and quizzes are given for student’s learning, understanding, and information. Three major categories of manufacturing processes covered in virtual lab are- sheet metal operations, metal cutting, and deforming processes. At the end of every lab, a quiz for practice is given where students can check their scores immediately. All animations showing various manufacturing processes are developed in house. An indigenously developed video is also included in the machining lab for a better explanation of the turning process.
Figure 1. Graphic user interface of manufacturing engineering virtual lab
3. Evaluation and Discussion

After the students have gone through virtual lab learning management system, a survey where they provided feedback on virtual lab and the benefits they have drawn, was conducted. The purpose of this Industry 4.0 virtual lab survey was to gather honest, anonymous feedback from the students regarding their experiences of virtual lab learning management system and its effectiveness for knowledge enrichment, and explaining and understanding subject contents.

The questionnaire was distributed to BEngTech Industrial Engineering first year students during a contact session of mechanical manufacturing engineering module. The questionnaire consisted of ten mandatory quantitative questions on content quality and presentation of virtual lab learning management system, and a further set of ten more questions on effectiveness of the virtual lab. The questionnaires were completed by a total of 62 students out of the total class strength of hundred and eleven.

The following response set was used by the students to respond the questions asked:

- 5    Strongly agree
- 4    Agree
- 3    Disagree
- 2    Strongly disagree
- 1    Not applicable

Figures 2 and 3 are graphical presentations of the feedback results on Industry 4.0 virtual lab survey. The results of both the mandatory and selected additional questions are shown in Tables 1 and 2, where the percentage and number of student responses are also recorded. It is observed from the feedback shown in Figures and Tables that almost 90% students were agreed and strongly agreed with the quality of the virtual lab learning management system and its effectiveness for their enhanced learning. It is worth mentioning that the very first message via this virtual lab to the students was regarding the 4th industrial revolution or industry 4.0, and as the feedback shows, they responded very well i.e. they knew beforehand about the 4th industrial revolution. The question statement ‘The animations and videos well represent and explain the manufacturing processes’ was well responded by the students where twenty eight students were strongly agree and thirty one were agree. Similarly, majority of the class i.e. 58 students were agree or strongly agree on the aspect that the virtual lab helped them to achieve learning outcomes of the manufacturing module. Furthermore, 90 % of the students found quizzes given at the end of lab, interesting and knowledgeable. It was also acknowledged by the students that the learning management system of the virtual lab is quite user-friendly. However, there are some concerns regarding the links and navigations in virtual lab system that have been noted for rectification and further development.
Figure 2. Questions on virtual lab learning management system
Figure 3. Questions on effectiveness of virtual lab
Table 1 Question statements distribution on learning management system of virtual lab

<table>
<thead>
<tr>
<th>QUESTION STATEMENTS</th>
<th>Not applicable</th>
<th>%</th>
<th>Strongly disagree</th>
<th>%</th>
<th>Disagree</th>
<th>%</th>
<th>Agree</th>
<th>%</th>
<th>Strongly agree</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The appearance and presentation of virtual Lab learning management system is good</td>
<td>0</td>
<td>1,61</td>
<td>2</td>
<td>3,23</td>
<td>32</td>
<td>51,61</td>
<td>27</td>
<td>43,55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. It preliminarily introduces Industry 4.0, therefore I know beforehand what 4th industrial revolution is, and its requirements and my role</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>29</td>
<td>46,77</td>
<td>33</td>
<td>53,23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. It is easy to access</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>3,23</td>
<td>39</td>
<td>62,90</td>
<td>21</td>
<td>33,87</td>
</tr>
<tr>
<td>4. The links and options correctly navigate to the appropriate pages and contents</td>
<td>0</td>
<td>2</td>
<td>3,23</td>
<td>4</td>
<td>6,45</td>
<td>40</td>
<td>64,52</td>
<td>16</td>
<td>25,81</td>
<td></td>
</tr>
<tr>
<td>5. The theoretical contents are fine and arranged sequentially</td>
<td>0,00</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1,61</td>
<td>43</td>
<td>69,35</td>
<td>20</td>
<td>32,26</td>
<td></td>
</tr>
<tr>
<td>6. The illustrations are clear and well represent the manufacturing operations, parts, machines and tools</td>
<td>0,00</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1,61</td>
<td>36</td>
<td>58,06</td>
<td>25</td>
<td>40,32</td>
<td></td>
</tr>
<tr>
<td>7. The quality of the animations is good</td>
<td>0,00</td>
<td>1</td>
<td>1,61</td>
<td>4</td>
<td>6,45</td>
<td>36</td>
<td>58,06</td>
<td>22</td>
<td>35,48</td>
<td></td>
</tr>
<tr>
<td>8. The animations and videos well represent and explain the manufacturing processes</td>
<td>0</td>
<td>0,00</td>
<td>1</td>
<td>1,61</td>
<td>2</td>
<td>3,23</td>
<td>31</td>
<td>50,00</td>
<td>28</td>
<td>45,16</td>
</tr>
<tr>
<td>9. The quizzes are well formulated, interesting, and knowledgeable</td>
<td>0</td>
<td>0,00</td>
<td>1</td>
<td>1,61</td>
<td>4</td>
<td>6,45</td>
<td>29</td>
<td>46,77</td>
<td>28</td>
<td>45,16</td>
</tr>
<tr>
<td>10. I am satisfied with the overall learning management system of the Industry 4.0 manufacturing engineering virtual lab</td>
<td>1</td>
<td>1,61</td>
<td>1</td>
<td>1,61</td>
<td>2</td>
<td>3,23</td>
<td>35</td>
<td>56,45</td>
<td>23</td>
<td>37,10</td>
</tr>
<tr>
<td>QUESTION STATEMENTS</td>
<td>Not applicable</td>
<td>%</td>
<td>Strongly disagree</td>
<td>%</td>
<td>Disagree</td>
<td>%</td>
<td>Agree</td>
<td>%</td>
<td>Strongly agree</td>
<td>%</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------------</td>
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<td>----------------</td>
<td>----</td>
</tr>
<tr>
<td>It helped to build my skills and competencies required to make contributions towards fourth industrial revolution</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td>2</td>
<td>3.23</td>
<td>31</td>
<td>50.00</td>
<td>29</td>
<td>46.77</td>
<td></td>
</tr>
<tr>
<td>I want all other modules should also be taught with the help of virtual labs</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td>1</td>
<td>1.61</td>
<td>25</td>
<td>40.32</td>
<td>36</td>
<td>58.06</td>
<td></td>
</tr>
<tr>
<td>It helped me to develop conceptual understanding</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td>2</td>
<td>3.23</td>
<td>39</td>
<td>62.90</td>
<td>21</td>
<td>33.87</td>
<td></td>
</tr>
<tr>
<td>The virtual lab system helped me to understand theory in practical ways</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td>5</td>
<td>8.06</td>
<td>40</td>
<td>64.52</td>
<td>17</td>
<td>27.42</td>
<td></td>
</tr>
<tr>
<td>I find virtual lab more effective than recommended books</td>
<td>0.00</td>
<td>2</td>
<td>3.23</td>
<td>2</td>
<td>3.23</td>
<td>39</td>
<td>62.90</td>
<td>19</td>
<td>30.65</td>
<td></td>
</tr>
<tr>
<td>I find virtual lab very supportive to pass the module</td>
<td>0.00</td>
<td>1</td>
<td>1.61</td>
<td>1</td>
<td>1.61</td>
<td>35</td>
<td>56.45</td>
<td>25</td>
<td>40.32</td>
<td></td>
</tr>
<tr>
<td>It helped me to better prepare for the exams</td>
<td>0.00</td>
<td>1</td>
<td>1.65</td>
<td>4</td>
<td>6.45</td>
<td>37</td>
<td>59.68</td>
<td>20</td>
<td>32.26</td>
<td></td>
</tr>
<tr>
<td>It helped me to achieve the learning outcomes of this module</td>
<td>0</td>
<td>0.00</td>
<td>0</td>
<td>0.00</td>
<td>4</td>
<td>6.45</td>
<td>32</td>
<td>51.61</td>
<td>26</td>
<td>41.94</td>
</tr>
<tr>
<td>It enhanced my learning</td>
<td>0</td>
<td>0.00</td>
<td>0</td>
<td>0.00</td>
<td>4</td>
<td>6.45</td>
<td>30</td>
<td>48.39</td>
<td>28</td>
<td>45.16</td>
</tr>
<tr>
<td>The virtual lab developed by the lecturer helped me to understand the module contents better</td>
<td>0</td>
<td>0.00</td>
<td>1</td>
<td>1.61</td>
<td>2</td>
<td>3.23</td>
<td>36</td>
<td>58.06</td>
<td>23</td>
<td>37.10</td>
</tr>
</tbody>
</table>
4. Conclusions

Various aspects of the development of Industry 4.0 virtual lab for manufacturing engineering education at University of Johannesburg have been discussed in this paper. Evaluation of student’s feedback and its analysis are presented. The following conclusions can be drawn from this work:

- Industry 4.0 manufacturing engineering virtual labs were developed successfully.
- A significant majority of the students were agreed on the appearance and functioning of the virtual lab learning management system.
- The students agreed that their learning and understanding enhanced after going through the virtual lab contents for various topics of manufacturing engineering module.
- Recommendations and qualitative feedback from the students have been noted for further development of virtual labs.

Avenues for future work include virtual labs for other manufacturing processes, evaluation and assessment of the lab based on focused group interviews, further development of trigger based labs, and their extension for other advanced manufacturing engineering subjects.

Acknowledgement

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References

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Biography

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. He has authored several SCI/ISI Journal and International Conference articles. He also authored and edited 10 international books on hybrid machining, advanced gear manufacturing, micro and precision manufacturing, and
sustainable manufacturing with the renowned international publishers. He has also successfully guest edited special issues of a Scopus indexed journals and he is currently editing a series of handbooks on Advanced Manufacturing as a series editor. He is a recognized reviewer of many international journals and in the advisor/technical committees of international conferences. He has also delivered invited speeches in international conferences and symposiums, and seminar talks at international universities. Kapil Gupta is a NRF [National Research Foundation] rated Researcher in South Africa. Currently, he is supervising some postdoctoral fellows and postgraduate students who are busy conducting research in advanced manufacturing and industrial engineering fields. He has obtained PG Diploma in higher education and conducting research in engineering education. He is working on implementation of innovative teaching techniques for the enhanced learning of engineering students. Recently, he also developed a manufacturing engineering virtual lab.