Implementing Industry 4.0 Teaching principles in Industrial Engineering Laboratories

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Abstract
Laboratories in education bridge the gap between theory and practice, by providing a simulated work environment. The quality and technological level of laboratory equipment and machinery must keep abreast with state of the art technologies in order to adequately prepare graduates for projected skills proficiency requirements by industry in the medium to long-term future. Sustained lab equipment upgrades are critically important. The developing Industry 4.0 technologies has highlighted the urgent need for lab equipment upgrades in Universities. We evaluate the Technology Readiness Level towards 4IR implementation of an Engineering laboratory at a University in South Africa. We present a migration strategy framework towards full Industry 4.0 compliance for the laboratory.

Keywords
Industry 4.0, Technology Readiness Levels, OPC AU and Engineering Education

1. Introduction
Engineering students need to be adequately prepared for the diverse workplace environment (Schuster, Groß et al., 2016). Industry 4.0 presents unprecedented demands on student education and training (Terkowsky et al., 2019). Literature has revealed the importance of appropriate laboratories in higher education towards addressing skills requirements for the workplace in world 4.0 (Terkowsky et al., 2019). Laboratories in most Industrial Engineering (IE) departments in South African institutions are still lagging in training the current students for the industry 4.0 workplaces (Sackey et al., 2020). Failure to adequately prepare students would render the South African students unemployable with dire consequences to the economy. Universities worldwide are gradually developing industry 4.0 compliant laboratories (Hernández-de-Menéndez et al. 2019; Zarte et al. 2016; Széll 2019).

This paper aims to develop a migration strategy framework towards building industry 4.0 compliant laboratories in order to facilitate the transition towards 4IR compliant engineering laboratories. In the process we evaluate current technological state, state of readiness towards industry 4.0 implementation as well as recommend a transition framework towards 4IR compliance
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1.1.Objectives
The following research objectives would facilitate the achievement of this aim.

OB1. To develop a migration strategy for building industry 4.0 compliant Industrial Engineering laboratories.
OB2. To assess the state of industry 4.0 compliance within the Industrial Engineering laboratory at the University of Johannesburg.
OB3. To recommend suitable systems and technologies required to achieve industry 4.0 compliance.

2. Literature Review
Industry 4.0 in engineering education alternatively, Education 4.0 is the development of industry 4.0 concepts towards digitalizing the HEIs (Neaga 2019). Industry is progressively upgrading its infrastructure towards 4IR. The need arises for HEIs to review undergraduate curricula and laboratory facilities to adequately prepare graduates for the industry 4.0 workplace (Coskun, 2019, Kayikci et al, 2019). The need too to pair theory and practice is more urgent (Bye & Osen, 2019). A secondary purpose of a laboratory is the ability to run trial tests and technology transfer for up to TRL 4 (Viegas, et al., 2018)

Germany and USA have recorded significant progress towards equipping their students with relevant theoretical and practical knowledge towards the industry 4.0 workplace (Terkowsky, et al. (2019). The training gap relative to institutions in developing countries is widening. The practical laboratory should develop eligible engineers to the extent that they need minimal on job training (Bye, (2019) .

The Technology Readiness Assessment (TRA) is vital when selecting which technology to invest in or procure new technology (Altunok, Cakmak 2010). Industry 4.0 compliant engineering education laboratories may be achieved at TRL 6 by using real industrial components (Zarte, Pechmann et al. 2016). A standard educational 3D printer could only score TRL 1 (Galetto and Peroncini, 2018). The higher the TRL score the more expensive the laboratory equipment gets (Hernández-de-Menéndez, Vallejo Guevara et al. 2019).

Digital communication at enterprise level is a critical enabling factor in 4IR. OPC AU (unified architecture) as depicted in figure 1 is communication protocol enables standardized and secure communication from the field level up to the enterprise level Széll (2019). Additionally, it collects data and models reliable information between the shop floor and the management (Széll 2019).

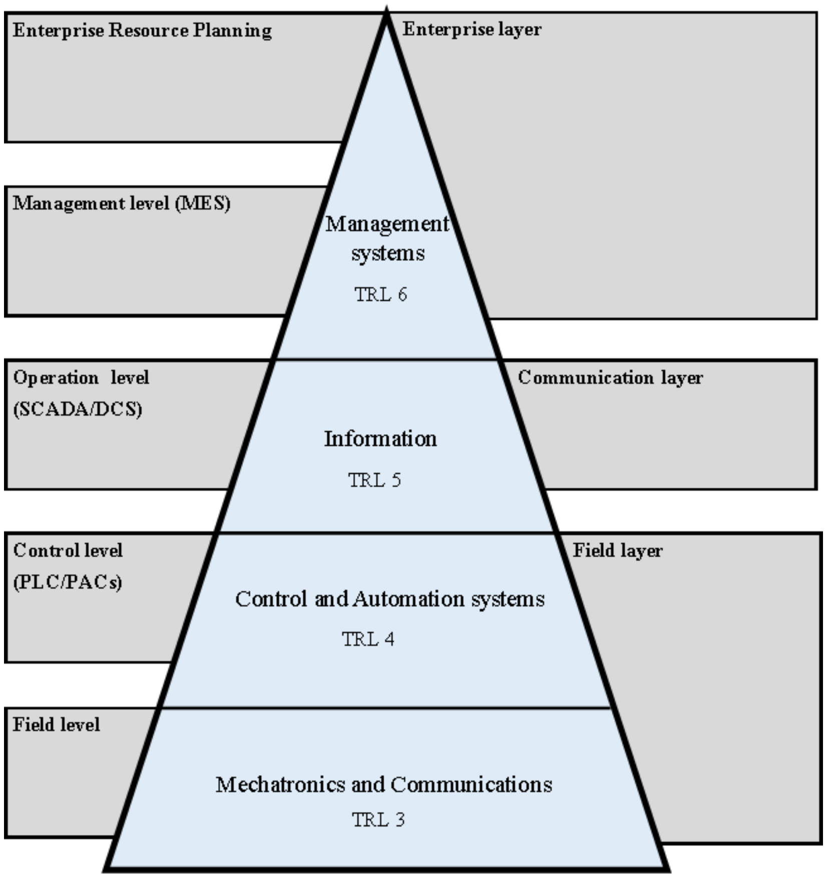

Figure 1 A Redesigned OPC AU architecture, adapted from Zarte et al.(2016),

3. Methods

In this paper we apply the case study methodology conducted in a real-life setting of a university to realise the objectives of this article. We adopt the industry 4.0 systems used by Zarte. We note however that availability of technologies may differ across regions and availability of suppliers (Elkaseer, et al., 2018).

We apply the Industry 4.0 assessment tool (table 3) for assessing the current state of the laboratory under study. The first table (table 3) represents a checklist to select different technologies categorized according to industry 4.0 systems (Zarte, et al. (2016). Table 1 is an adapted TRL dashboard. It is illustrates the number of technologies available and the cumulative percentage rating of technologies selected.. Table 5 represents a reconfigured TRL index embedded with the OPC AU architecture (Széll (2019) , (Zarte, et al. (2016).

$$T_t=\left(\frac{T_s}{T_a}\right)x100 \quad (1)$$

Where T_t = total accumulative percentage per system
T_s = total selected technologies per system
T_a = total available technologies per system

The last column in Table 5 represents the TRL outcome. Binary representation is applied, with 1, representing TRL satisfied.

Table 4 reflects the TRL index embedded with the OPC architecture and industry 4.0 systems. It provides a sequential process for implementing the relevant industry 4.0 compliant technologies per TRL level. The overall compliance is measured by first determining the total TRL scored using the formula below

$$T_{trl}=\left(\frac{S_{trl}}{A_{trl}}\right)x100 \quad (2)$$

Where T_{trl} = total TRL score
O_{trl} = total TRL Obtained
A_{trl} = total TRL available

The actual compliance status is determined by the following if statement
If
The TRL score is = 100%, Then Display “Compliant” otherwise “Not Compliant”

The assessment tool is designed to assess the technology readiness levels and industry 4.0 compliance state of different laboratory designs. The laboratory design at in the IE laboratory at UJ consists of both physical, virtual production systems and a logistics lab. The existing lab equipment/software are summarised in table 1.

Table 1 Lab equipment in the IE laboratory at UJ

Hardware	Controller	Software
1x Mitsubishi 6-axis industrial robot type RV-4FL	Robot controller CR750-D & Teach box R56TB	1x CIROS 6.4 Software, 1x Studio, 48x Educational
1x Application Module Stacking Magazine	1x Control panel with emergency stop	AnyLogic simulation software
Parallel-Series Pump system	Festo 7" CDOX operator unit HMI	EzOPC server
13x 3D Printer	2x EduTrainer® Compact CECC LK PLC	Codesys PLC software
Analog-in/out converter-BNI IOL	3x DC motor controller (VFD)	
19" module 4AIN/2AOUT (6 HP)	Voltage Signal Conditioner, Analogue	
Sensors: Flow rate, pressure, temperature	PID & Data acquisition	
MPS sorting station		

4. Data collection

The IE laboratory at UJ has enough lab equipment for the field level. It is essential to check field-level devices' ability to enable data exchange and communication across all the OPC AU architecture levels. This will enable universities to archive industry 4.0 compliance with less equipment at much lower capital investment and enable phased investment/upgrades. At least 90% of the minimum number of technologies was achieved for Mechatronics systems.

For communication, control and automation systems, the only technologies lacking in the IE laboratory are camera-based quality control and RFID technology. The laboratory scored 80%. At the time of this research project, the laboratory was still commissioning the SCADA systems. The lab does not possess any remote control equipment.

The only parameter that can be measured in the laboratory is temperature, and for management systems, the laboratory installed the simulation software in the computer laboratory. There is currently no link between the shop floor and the management system technologies.

Table 2 Industry 4.0 systems and technologies checklist

Mechatronics		**Communication and Control and automation systems**				**Information**		**Management systems**	
Input and output m**odules**	☑	Ethernet/Fieldbus/ TCP/IP	☑	PLC control	☑	Meetings	☐	ERP software	☐
robotic arms	☑	RS232/48	☑	Camera-based quality control	☐	Orders	☐	Database	☐
AS and RS warehouse	☑	OPC-UA.	☑	RFID technology;	☐	Energy consumption	☐	MES	☐
Transport systems	☑		☐	Robotic control system.	☑	Deliveries	☐	e-PPS	☐
Pick and place system(s)	☑		☐	Variable Speed Drives (VFD/VSD)	☑	BOM	☐	MMS	☐
Sorting station (s)	☑		☐	PID technology	☑	Warehouse traffic	☐	DSM	☐
Sensors	☑		☐	HMI	☑	Market scenarios	☐	SRM	☐
LED Indicators	☑		☐		☐	Maintenance	☐	CRM	☐
Sire alarm	☑		☐		☐	SOP	☐	Simulation software	☑
Wires	☑		☑		☐	Temparature	☑		☐
	☐		☐		☐	HMI/SCADA	☑		☐
Total %	100%	**Total %**			90%	**Total %**	18%	**Total %**	11%

5. Results and Discussion

It is important to note that the users can adjust the minimum percentage of technologies required at each technology readiness level according to the type of laboratory and quantity of equipment they wish to build. The TRL dashboard table 4 illustrates that the lab achieved TRL 3 and TRL 4. The results in table 5 represent the TRL achievement.

Table 3 TRL dashboard

TRL	Number of Technologies at this TRL	Minimum % of technologies required at this TRL	Actual % of technologies obtained at this TRL	Was this TRL achieved 1=yes 0=no
3	9	90%	90%	1
4	10	67%	80%	1
5	10	100%	18%	0
6	9	67%	11%	0

Table 4 TRL index

Levels	Description	Outcome	Systems Categories
TRL 1	No laboratory equipment.		
TRL 2	Basic and affordable Lab equipment that only connects with lab desktops using USB cables to demonstrate basic principles. Simulation and modeling,		
TRL 3	**FIELD LEVEL Actuators and sensors** The system lacks integration and sorting stations, transport systems, and automatic storage/retrieval systems. Connection is made through serial Fieldbus or Ethernet cables	Obtained	**Mechatronics/Communication**
TRL 4	**CONTROL LEVEL (PLC)** Consist dedicated industrial PLCs and HMIs to control complex May industrial controller to control a robot.	Obtained	**Control and automation systems**
TRL 5	**SCADA/HMI** Systems with image processing capabilities, RFID technologies, web service-based interfaces, and OPC. It might require the construction of a new building. System interlinked through sensors. System consist of HMIs and SCADA	Not Obtained	**Information**
TRL 6	**MES AND ERP** Use of industrial components, real-time connectivity, and exchange of data between the shop floor machinery, product, simulation, database, MES and the ERP system	Not Obtained	**Management systems**
	Total TRL score	50%	
	Laboratory compliance	Not Compliant	

5.1.Proposed Improvements

Cutting edge technology laboratory is very costly. Phased but sustained laboratory upgrade strategies are recommended. Virtual augmented reality software offers potentially cheaper laboratory design. Further work on the feasibility of this option is recommended.

5.2.Validation

The assessment tool presented in this article may serve as a guideline when developing both physical and virtual production systems & logistics laboratories. It allows the user to define the type of laboratory they wish to achieve and amend the technology list under each industry 4.0 system. Additionally, it allows users to record the technologies their current laboratory possesses. Finally, the assessment tool provides an integrated representation of the TRL outcomes, OPC AU architecture levels, industry 4.0 systems, and the industry 4.0 compliance all in one table. The assessment tool presented in this article was utilized to the industry 4.0 compliance state of the IE laboratory at UJ. Moreover, the results were found to declare the current state of the laboratory as non-compliant at TRL 4

6. Conclusion

This article seeks to address the lack of an industry 4.0 compliance assessment tool by developing a comprehensive assessment tool for building Industrial Engineering laboratories. It presented an industry 4.0 compliance assessment tool and was successfully implemented to assess the compliance of the IE laboratory at UJ. The assessment tool results declared the IE laboratory at UJ a non-industry 4.0 compliant. Moreover, the assessment tool gives provision for users to fulfill the TRLs at any level, as dictated by budgetary provisions.

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