E-ISSN: 2717-2937 | P-ISSN: 2783-1337

International Journal of Research in Industrial Engineering

IJRIE

www.riejournal.com

Int. J. Res. Ind. Eng. Vol. 10, No. 4 (2021) 358–370.

Paper Type: Research Paper

Harmonisation of the Engineering Disciplines Enhanced by the Learning Factory

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Citation:

Malele, V., & Mafu, M. (2021). Harmonisation of the engineering disciplines enhanced by the learning factory. *International journal of research in industrial engineering, 10* (4), 358-370.

Received: 16/09/2021 Reviewed: 14/10/2021 Revised: 09/11/2021 Accepted: 17/12/2021

Abstract

All engineering graduates must possess specific essential competencies when leaving universities to transition to the industry or be successful in the world of work. This paper adopts a literature review approach to synthesise available secondary data regarding creating harmony among engineering disciplines. It uses the illustration of a vending machine to indicate how various engineering disciplines could be harmonised through the Learning Factory platform. Moreover, it provides some ideas for harmonising engineering disciplines. The main findings of this work suggest that the Learning Factory concept is a critical ideology that is worth implementing, especially by developing. The Learning Factory environment can produce well-rounded graduates capable of applying technical and non-technical skills to solve community challenges, including being entrepreneurial and innovative to drive economic growth and development. The paper concludes by providing insights demonstrating that the concept of a Learning Factory can also be utilized for addressing other engineering and industrial-related challenges.

Keywords: Harmonisation of engineering disciplines, Learning factory, Vending machine, Industry–ready graduates, Knowledge transfer, Problem-solving, Engineering education.

1 | Introduction

Traditionally, engineers are perceived as problem solvers (i.e., people trained to apply the knowledge of mathematics and science to solve problems) [1] and [2]. Engineers could apply their problem-solving, investigation, analytical skills and methods for the provision of clean water, improved farming techniques and automated intelligent systems which result in improved production of goods and services, innovation of better and cheaper building materials which could help provide shelter for people and also increase ease of building houses, thus afford a better standard of living for communities. Therefore, applying relevant engineering and scientific skills, can potentially solve long-standing community challenges, thus warding off poverty and increasing economic growth and development. On the bigger picture, communities are part of a country, so an increase in their economic growth ideally leads to an overall increase in the overall country's economic growth. Subsequently, this will assist countries under study by closing the unemployment gap, increasing economic growth and development, and allowing developing countries to catch up with others.

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http://dx.doi.org/10.22105/riej.2021.314637.1265

When a community's problems are solved, in general, their standard of living improves and thus reduces poverty [3] and [4]. In the bigger picture, efforts to ease poverty in a community implicitly lead to economic growth, aiding communities to catch up with others. In order for engineering to achieve the goals of assisting countries to catch up, the different engineering disciplines must come into harmony [5]. In this paper, a Learning Factory (LF) concept is presented as a strategic tool in an industry-simulated environment where students and academics could experience the benefits of harmonisation of engineering disciplines. An industry-simulated environment is an environment that allows the integration of different engineering disciplines to work alongside other technical and non-technical disciplines, such as leadership and management [6]. In this regard, the LF concept would be discussed as a strategy that could foster the harmonisation of the engineering disciplines.

Apart from this introductory statement, this paper is organised as follows: Section 2 highlights the employed research methodology, while Section 3 explores the need to harmonize engineering disciplines. Section 4 discusses the LF conceptual framework. Notably, we describe the LF concept, demonstrate how it can be applied in an educational setting, and illustrate the harmonization of different engineering disciplines and the LF concept using a vending machine. Moreover, we provide a brief history of the LF and its existence in South Africa and Botswana. In Section 5, we discuss challenges and provide some recommendations. Finally, section 6 provides a conclusion to this paper.

2 | Method

This paper adopts a qualitative research approach through a relevant literature review to synthesise available secondary data regarding the concept of creating harmony among different engineering disciplines for economic growth. It uses a vending machine to illustrate how engineering disciplines could be harmonised and what students could learn if this harmony could occur in the LF.

Using a qualitative approach emanates from the purpose and concept underlying this research, i.e., the importance of harmonizing different engineering disciplines and the LF model in the context of catch-up effect and global value chains. Moreover, this research is concerned with the subjective assessment of attitudes, opinions, and behaviour. Therefore, a qualitative study will afford the investigation of the primarily disconnected nature of knowledge interactions, i.e., harmonization of different engineering disciplines, catch-up effect, global value-chains [7].

Using various search terms and keywords related to harmonizing engineering disciplines and learning factories at universities, we conducted searches and collected related full-text manuscripts. This was followed by developing inclusion and exclusion criteria to identify relevant citations and identified information applicable to our research objectives. Subsequently, we reviewed studies on the harmonization of engineering disciplines and the LF. Thus, these research approaches will improve understanding of all these phenomena and probe new perspectives.

3 | Harmonisation of Engineering Disciplines

Over recent years, various works on the harmonisation of engineering disciplines have been undertaken. In the context of this work, harmonization of engineering disciplines refers to the process of integrating different engineering disciplines to produce a coordinated and consistent engineering discipline that balances theoretical and practical knowledge to afford students a practical experience and understanding of the full range of issues involved in product design, manufacturing planning, fabrication assembly and testing of functional products [8] and [9]. In a way, the harmony of the engineering disciplines involves engineers from different disciplines (or even within the same discipline) or different countries, or different value chains merging their skills to solve challenging issues, revolutionize industries and create employment. On the other hand, the harmonization concept seeks to determine minimum skills that must be possessed by an engineer so that they can contribute positively to the industry and subsequently grow the economy. Notably, the need to transfer knowledge across different organizations, adapt to different work environments, and assimilate information underlines the need to harmonize the engineering disciplines.

Howard [10] argues that written communication skills are essential for engineers in the workplace yet developing these skills in undergraduate engineering continues to be a significant challenge. In response, Howard [10] proposed that curriculum innovation that integrates written tasks in engineering courses through online writing tools should be provided to students to harmonise engineering disciplines. Accordingly, they proposed creating an integration model based on a risk communication framework in collaboration with leadership, learning support, and academics.

Birch et al. [11] presented a methodology and toolkit for analysing multidisciplinary engineering models to help practitioners maximise the utility of complex models that were extracted, visualised and analysed through interdisciplinary computing and metrics. These methods expose, manage and reduce model complexity and risk while supporting engineers in optimising efforts and providing insight into the multidisciplinary model composition.

On the other hand, Mordinyi et al. [12] point out that harmonising or combining the efforts of various engineering disciplines is essential when engineers are expected to develop and implement large engineering projects. This is because each engineering discipline utilizes specific engineering tools and data model concepts representing interfaces to other disciplines. Therefore, integrating these different engineering disciplines opens more opportunities for innovation and possibly leads to the realisation of novel products which may be commercialised, thus opening up possibilities for creating economic wealth.

Moreover, Craig [13] records that through his 25-years of experience as an engineering educator, researcher, and consultant, two dilemmas faced by companies could be identified as: (i) senior engineers with experience and integrated know-how are retiring and taking with them the core competencies, and the new engineers have no multidisciplinary, integrating, systems experience; and (ii) academia does not teach integrated know-how leading to failure for the engineers to have multidisciplinary harmonised engineering experience. These two lead to the loss of competitive advantage, making companies question how they can effectively and efficiently capture engineering expertise and enhance the engineering workforce to keep on the competitive advantage. As a way forward, these companies decided to send some of their young engineers to study towards a Masters' degree. Unfortunately, they found that most Masters' degrees usually consist of 8-10 courses and an additional short research project with very theoretical and little integration or practical applications. Secondly, the cost and time commitment are very high. Engineers still need to work full-time while having other social responsibilities, for instance, taking care of their families. Consequently, Craig [13] proposed that a solution to these two dilemmas could be a renewed focus on multidisciplinary, model-based systems engineering and a paradigm shift in how education for a practising engineer is delivered.

Due to the growing number of requirements and the introduction of new technologies, current trends indicate that more engineering disciplines are involved in multidisciplinary system design. Zheng et al. [14] studied how to achieve an integrated design for multidisciplinary systems using the knowledge-based engineering approach that focuses on designing and implementing the partial discharge detection system and a belt conveyor system. They found that some of the unnecessary iterations could be resolved by interfacing multidisciplinary disciplines, resulting in a concurrent design process that harmonised different engineering disciplines during the detailed design phase. Thus, this displays the potential of harmonising engineering disciplines in providing solutions to long-standing challenges in work environments. However, in [10]-[14], propositions do not speak to the immediate need of supplying industry with industry-ready graduates who could be trained in an academic-industry simulated environment while still enrolled at university. Therefore, to produce industry-ready graduates who could appreciate the harmonisation of engineering disciplines, students should be trained in an academic-industry simulated environment while continuing with their university curriculum.

4 | Learning Factory

Several definitions of the term "Learning Factory (LF)" have been proposed within the community. According to [15]-[17] a LF refers to a learning environment specified by processes that are authentic, include multiple stations, and comprise technical as well as organizational aspects, a setting that is changeable and resembles a real value chain, a physical product being manufactured, and a didactical concept that comprises formal and non-formal learning, enabled by own actions of the trainees in an on-site learning approach.

The LF was founded on three beliefs: lecturing alone is not sufficient, students benefit from interactive, hands-on experiences and experiential, team-based learning involving student, faculty and industrial participation enriches the educational process and provides tangible benefits to all [18] and [19]. These collaborations and experiences provide students with vast opportunities and preparedness to tackle real-world challenges and provide better insights into their solutions [20]. Besides the hands-on experience on different industrial models, methods and processes after comprehending theoretical concepts in the classroom, students access state-of-the-art machinery and equipment and processes to input new ideas [21]. For instance, through university-industry collaboration, the industry can provide facilities for students to conduct their project work. Thus, it provides a conducive learning environment where processes and technologies are based on an accurate industrial site, allowing a direct approach to the product creation process. They are, in fact, based on a didactical concept featuring experimental and problem-based learning [22].

On the other hand, these collaborations allow industries to remain at the forefront of technology through research that university students and researchers undertake. Through research, it became eminent that experiential learning has more significant benefits than the usual traditional teaching method without showing or practically guiding them [23]. The latter teaching and learning approach could easily be facilitated by an academic-industry simulated environment that may replicate a factory where students practically assimilate real-world processes and activities. This academic-industry simulated environment is known as the LF. Besides the type or purpose of the LF, learning broadly takes place through teaching, training and research.

The LF concept promotes the ideology in which engineering disciplines work alongside other technical and non-technical disciplines [6], [24], [25]. It integrates different teaching methods to move the teaching-learning processes closer to real industrial problems [24]. According to [26], the main goals of the LF are either technological and organizational innovation (if used for research) or an effective competency development (if used for education and training), i.e., the development of participants' ability (including motivational and emotional aspects) to master complex, unfamiliar situations. Moreover, the [27] argues that the objective of an LF is to integrate a practice-based engineering curriculum that balances analytical and theoretical knowledge with physical facilities for product realization in an industrial-like setting. Therefore, the LF model emphasizes practical experience; therefore, Engineering Technology (ET) and other programs that emphasize hands-on experiences for students are well suited to implementing the LF model. Therefore, to achieve such goals, the LF standard structure comprises six dimensions and corresponding features, and these are illustrated in *Fig.1*. These dimensions consist of purpose, process, setting, product, didactics and operating model.

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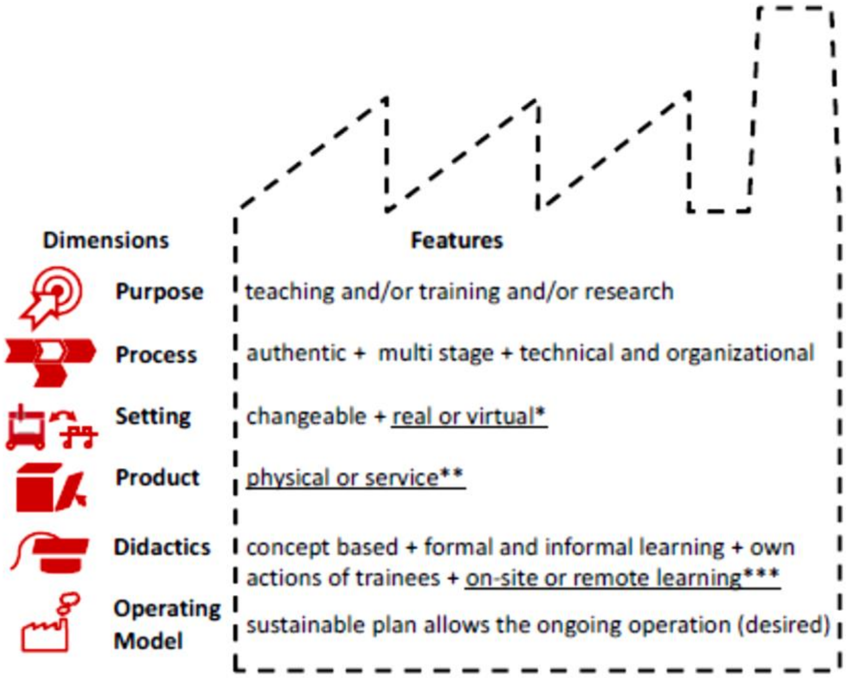

Fig. 1. The six dimensions of the LF [26].

While the LF concept can be implemented in various ways; however, in the broadest sense, it is further away from reality and less hands-on though it offers advantages regarding the scalability, location of independent use, or a widened scope of addressed problems. These are modified in at least one of the following directions: (a) virtual representations of valu-added chains; (b) connection of trainees to the learning processes based on remote information and communication technology connections, and (c) product which comes in the form of a service. In the narrow sense, the LF provides an entire value chain for a physical product in which participants can perform, evaluate, and reflect on their actions in an on-site learning approach [26] and [27]. The LF covers various learning environments that provide a reality-conformed production environment where only minor abstractions are possible concerning the industry [23], [26], [28]. For example, [26] highlights and discusses six varieties of LFs scenarios to show that no LF usually resembles another or is used in the same way. The LF supports the idea that its concept could be applied in the education sector to create an environment where students would be oriented towards workplace problems [29] and [30]. This is illustrated by *Fig. 2*, which demonstrates the LF bridging the gap between students' laboratory experiments and industry work.

The authors [30] explain that in an LF environment, students attempt to solve a real-world problem using a systematic, integrative approach by applying various concepts they would have learned in their LF tailor-made modules. The problems could be holistic and complex, not unidirectional, thus affording students various options as solutions, necessitating the need to integrate different engineering concepts and develop a tailored solution that addresses the challenges at hand [31]. Moreover, in the LF, students perform some tasks that assist them in their future career paths and develop personal skills for building strong confidence in their future workplace. In this regard, the LF model pursues an action-oriented approach, with participants acquiring competencies through structured self-learning processes in a production-technological learning environment.

The LF has been used for educational purposes, research and training in areas such as manufacturing, energy efficiency, service operations and processes [32] and [33]. For example, [33] conducted a critical analysis of the plant processes to obtain all the required parameters to set up a simulated model of a

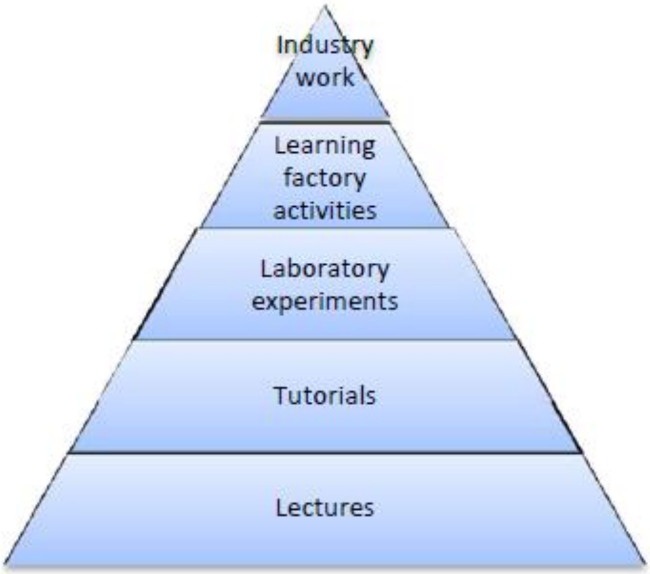

Fig. 2. The LF gap filling [29].

PLC controlled simulation for a coupled tank system based on an existing dual-tank educational process control plant. The authors argue that this kind of simulated platform uses existing standard industrial software and hardware that gives engineering students the necessary exposure to transition to the industry successfully. Also, it enhances learning capability because what is taught is no longer limited to only physically available equipment. Furthermore, such a platform solves other problems commonly faced in learning environments, such as limited resources and space constraints, by opening up the possibility of remote laboratories.

As a result, this demonstrates that the LF has a great potential of facilitating new learning approaches that allow training in a realistic manufacturing environment, modernize the learning process and bring it closer to the industrial practice, leverage industrial practice through the adoption of new manufacturing knowledge and technology, and boost innovation in manufacturing by improving work processes [26] and [33]. Furthermore, the LF promotes the capabilities that drive manufacturing competitiveness among young engineers [26]. These capabilities could include problem-solving capability, systems thinking capability, talent or creativity-based innovation. Moreover, LFs could enhance engineer outputs and orientation, gear them towards excelling in their studies and align them with their rightful engineering skills, including developing them into entrepreneurs and innovators. In this regard, it further proves that the LF is a critical strategic tool that universities and industries can use to harmonize engineering disciplines.

The design and physical building of LF could come with many challenges. However, the LF should be designed to achieve multiple objectives such as ease of roaming, display area, and special display areas [34]. Literature provides a guideline regarding ready-made designs. However, it might be difficult for a design student or graduate tasked to design the LF to choose a perfect design. Therefore, authors in [34] suggest the Analytical Hierarchy Process (AHP) as a suitable technique for comparing existing designs for the student or graduate designer to achieve and reach a decision of the final layout design selection.

5 | Discussion

5.1 | The LF in South Africa and Botswana

The literature points that the LF concept was initially coined in 1994 when the National Science Foundation (NSF) in the United States of America (USA) awarded a consortium led by Penn State University a grant to develop a "learning factory". In that regard, the Bernard M. Gordon LF was established as a state-of-the-art facility with a mission to help bring the real world into the classroom by providing engineering students with practical hands-on experience with industry-sponsored and client-based capstone design projects. The Bernard M. Gordon LF is illustrated in *Fig. 3*.

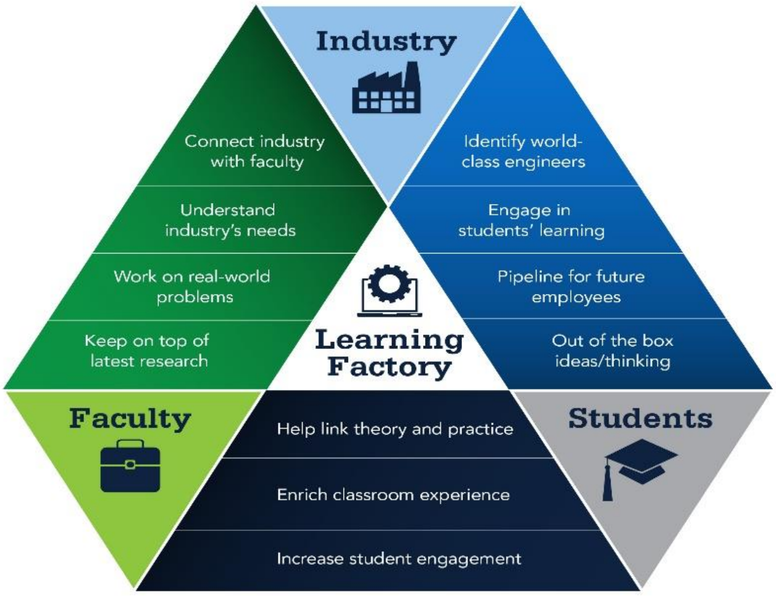

Fig. 3. The Bernard M. Gordon LF model. (Source: http://www.lf.psu.edu).

To use the Bernard M. Gordon LF, a student must be enrolled in an engineering course at the College of Engineering, Penn State University; and work on a course-related project. Due to University regulations, the LF cannot be used for personal work unrelated to a course. It is recorded that since its inception, the Bernard M. Gordon LF has completed more than 1,800 projects for more than 500 different sponsors, and nearly 9,000 engineering students at Penn State University Park participated in such a project. Since its inception, the use of LFs has increased widely, particularly in the USA and Europe, and has taken many forms of facilities varying in size and sophistication to enhance the learning experience of trainees in one or more areas of knowledge [26]. In South Africa, there is an indication of LF environments at Stellenbosch University (SU), Nelson Mandela University (NMU) and companies such as Nissan South Africa.

The Stellenbosch University Learning Factory (SULF) provides a supplementary educational method to cover the gap between abstract lectures in universities and practical experiences required in the workplace [29]. The SULF projects provide a similar real-life environment for students to gain practical and hands-on experience, which is not included in their current curriculum. It develops operations management methods, such as lean management, process optimization and change management, including soft skills such as communication, teamwork, project management, intercultural and leadership skills [29].

The LF in Logistics Management at NMU assembles different products such as skating boards with computer programmes (http://sms.mandela.ac.za/News/Prof-Horn-Participates-in-the-learning-factory-pro). Accordingly, students have to order all the individual parts, manage the inbound stock, to assemble, and adapt to on-time release on different work stations. Such training provides students with skills such as communication, project management, people management.

The Nissan South Africa, a car manufacturering company, has built a modern new LF centre at its vehicle manufacturing plant in Rosslyn, Gauteng Province. Its objective is to make a significant contribution towards assisting Nissan to meet the increasing demands for greater productivity, skills transfer, and global standards of quality by training and developing its employees. The new centre consists of sizeable modern lecture rooms, a computer training facility, and technical training workshops situated close to the plant and catered for the main assembly areas (paint, body and mechanical). It is envisaged that skills developed in the Nissan LF would contribute to meeting the objectives of the

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company's multiskilling programme and achieving the higher levels of quality required. Unfortunately, this LF is for NISSAN employees, hence not accessible to local universities.

In 2015, Fluor Botswana, a global engineering, procurement and construction company, opened an office in Gaborone, Botswana. The office serves as the company's operations base to expand and diversify business activities across sub-Saharan Africa. Through its international-based LF known as Fluor University, Fluor has implemented an employee development program that provides virtual training to its employees and their stakeholders worldwide. In addition, Fluor University consists of five virtual colleges: (i) construction and fabrication, (ii) project management, (iii) project controls, (iv) supply chain, and (v) engineering. In this setting, trainees have access to more than 200 instructor-led courses in traditional classrooms or through video distance learning. Fluor University is accredited by the International Association for Continuing Education & Training (IACET) to grant Continuing Education Units (CEUs) needed for professional certifications.

Fluor Botswana is also equipped with the required technology to allow individuals to access Fluor University's online, instructor-led and video distance learning. Thus, this indicates the LF environment found in Botswana, which is put in place to empower many Botswana employees (of Fluor and its stakeholders) and contribute to building a sustainable workforce in the country. Unfortunately, there is no indication of a strong relationship between Botswana's two public universities and Fluor University. Such a relationship is critical as it could assist in producing industry-ready graduates. Therefore, unlike in South Africa, where the LF is established within the university settings, an LF environment must be attached to Botswana universities.

5.2 | Illustration of Harmonization of Different Engineering Disciplines and LF Concept by Using a Vending Machine

Engineering brings together significant economic benefits and thrives on teamwork, which could be made possible by communicating ideas and exchanging knowledge. Harmonisation of engineering disciplines is critical as it could be the birthplace of systems and forums that allow engineers to interact and share ideas and knowledge to design and develop a client/user acceptable product or service. An immediate example of how an LF and harmony of engineering disciplines could be realised is by working together to create something novel and acceptable to a client or user can be demonstrated through the design, development and manufacturing of a vending machine system.

Consider an industry that aims to design and produce an intelligent vending machine; therefore, getting a good design and product requires, at the primary level, different mechanical, electrical, industrial and computer engineers, including project officers/managers, business development team and marketing teams.

In particular, to produce a vending machine, the following engineering disciplines could be vital:

The requirement or business analyst or product marketing engineer facilitates meetings with the industry that manufactures vending machines and gathers the necessary client's requirements. This engineer also interacts with potential users or customers to solicit more information, such as the look and feel of the vending machine. In the LF, the engineers mentioned above train students to gather the necessary data and information (through structured or unstructured interviews, questionaries) to manufacture the vending machine system. In addition, students learn various essential manufacturing techniques; for instance, before any system could be manufactured, its manufacturing specification must first be put into place.

By way of an example, the requirements engineer may develop a necessary flowchart that the software or product development engineer could use to design and provide the software code for the vending machine. As an illustration, such an engineer could represent the information for other engineers as follows: (i) the machine should accept coins from R1 to R5 and paper notes from R10 to R200; (ii) allow the user to select products Coke or sweets (iii) allow the user to get a refund or cancel the request if there is a need; (iv) return the selected product and remaining change if any; and (v) go back to the original purchasing stage or allow the reset operation for a vending machine supplier.

Since the latter requirement statement is the essential part of the problem, the requirements engineer assists students to read the problem statement multiple times to get a high-level understanding of the problem. The students should be trained to become aware that if requirements are unclear, they might mislead other manufacturing teams, and the final product might not meet user specifications. As a result, the training in the LF should be cyclic and interactive so that students gain a clear understanding of the client and user specifications.

A software or product development engineer needs to use object-oriented software languages (such as Java) to design, code and test the vending machine. Also, this engineer should produce design documents, working program code, and unit test results with this task. Hence, the latter tasks need the software or product development engineer to work alongside the business analysts or project engineers.

In the LF, the engineers, as mentioned earlier, train students to apply techniques of object-oriented language such as encapsulation, polymorphism or inheritance, and how to use an abstract class and interface while solving a problem or designing an application.

The role of mechanical engineers is to design the structure, motor and pump systems of the vending machine to keep the food fresh and drinks cold and deliver the product (food or drink) to the customer when a purchase is made. Some of these tasks might require the expertise of a structural engineer and a refrigeration engineer. For example, when a product is selected (i.e., a user interface designed by a software developer), a screw-shaped wire turns a coil forcing the item off its shelf and into the delivery shoot while avoiding too much pressure on the item else it would be damaged and too little pressure as it would get stuck.

In the LF, the mechanical engineer teaches students structural design techniques and dynamics of the cooling system, stress and strain through the necessary coil dynamics.

An electrical engineer designs and develops electrical regulators to keep food fresh and drinks cold and deliver a selected item. They achieve this by designing microcontrollers that run and monitor various vending machine systems. When a selection is made, the microcontroller sends a signal to a motor designed by the mechanical engineer, which enables payment and delivers the product (food or drink).

The microcontrollers monitor cooling systems, which keep the food fresh and drink cold. Too little power could mean jammed soft drinks and melted ice cream, but too much power could mean excessive electrical heat or burned-out circuitry. In the LF, students learn how to design and use electrical regulators and microcontrollers to facilitate a stable temperature within the vending machine and deliver the right product without losing its freshness.

An industrial engineer designs and develops the machine for accessibility, ease of use, and attractiveness and ensures all the necessary equipment or infrastructure is available. If some equipment is not available, the engineer will purchase it from other equipment providers or is designed or innovated from scratch. The industrial engineer decides on which part of the machine should be placed and how it should be oriented to achieve its goal in the design. They ask themselves questions like, what if a disabled person uses the machine, what if a child is making a purchase, is it intuitive to have the payment slot here or there.

In the LF, students learn from industrial engineers how to design and manufacture a sound system for a client and the user through agreeable satisfaction. The student will also learn how a logistic and supply chain or innovation process works. The student could learn how to create a software system that makes it easy for navigation when a selection is made, a secure method of money transfers and communication of the machine's status to the vending company at any time. Furthermore, in the LF, students could learn from the industrial engineers how to reduce waste on the design and development of the vending machine using 5S (i.e. a systematic approach that helps to organize a workplace for increasing efficiency and safety while reducing waste) and shadow boarding approach [35]. The latter could aid students to have a workshop/workstation tools organization technique. Finally, business developers, marketers and entrepreneurs could teach students how to use business processes to profit through the vending machine and its products.

Another example that could illustrate the harmonisation of engineering disciplines and be utilised in the LF to train students is a project that examines the strength of new material. Suppose the strength of new material is determined by a materials science engineer, skills for calculating the tensile and compressive forces that it experiences, and its resistance under these forces are derived from mechanical engineering. Determining the resistance of steel reinforcement inside a concrete block by a civil engineer again calls for skills from mechanical engineering. If this project is conducted in the LF, students will gain the same skills needed to fulfill the project goals.

It is generally a good practice to have engineers from different disciplines who possess core skills in the business of other disciplines to build a more robust human resource. This is beneficial because when presented with a problem, each engineer will contribute to the attainment of a solution. These engineers will also voice their shortcomings, where other engineers could meet those shortcomings by using knowledge from their discipline. The same approach could invite interested engineers to chip in on a project proposed by an engineer from a different discipline who needs other engineers' skills.

In the LF, good practice also increases the multi-criteria group decision-making problem. The latter could be achieved by utilising the Hypersoft set and Fuzzy Hypersoft Set (FHSS) [36], as it will deal with complex parametric data and vague concepts that could be contributed by participating engineers and students. The work by [36] illustrates how FHSS theory plays a role in solving real decision-making problems.

6 | Challenges and Recommendations

While the LF plays a pivotal role in enhancing university-industry collaborations, multi-disciplinary cooperation is not easy to achieve due to each collaborating organisation's inherent challenges. For instance, the current financial infrastructure and funding model at various institutions may render it difficult to allocate budgets for students to spend time in the industry. In addition, project-based learning is usually demanding by nature, particularly the interdisciplinary projects demand on researcher's time and other resources.

Moreover, the collaborating parties need to be realistic in selecting projects that they can work on together. Some projects may be exciting, but the teams must ensure that they have the necessary skills and expertise to undertake them within reasonable timelines. Based on the above initiatives, it can be argued that the LF is a paradigm shift to a university-industry partnership providing real-world problem-solving in engineering education. Therefore, we provide the following recommendations and outline the immediate benefits.

- *The industry as a partner: Industry should be involved at all educational stages (curriculum design, advisory board, project sponsorship, faculty experiences and financial support). Moreover, this will allow universities to match the degree of industry complexity to the learning objectives.*
- *Active learning: A proper environment will enable students to learn independently. The first-hand experience on real-world problems provides an opportunity to develop own skills and knowledge that are more memorable and transferable than in a lecture.*
- *Appropriate facilities to stimulate learning: The learning facilities must guarantee safety, be well-equipped, multidisciplinary (i.e., all students must have access regardless of their specializations) and be visually impressive.*

- *Formal educational training: In addition to their in-depth technical expertise, the engineering teaching staff must possess formal training in education. This will stimulate continuous and methodical improvements based on established and the latest educational principles and practices.*

7 | Conclusion

Africa is endowed with an abundance of natural resources. Instead of African countries benefitting from these resources, they are experiencing a resource curse, i.e., countries rich in natural raw material generally fail to realize rapid economic growth rates. The resource curse suggests that an abundance of raw materials can cause overvalued exchange rates, thus making exports less competitive, crowding out of other sectors of the economy leading to unbalanced growth and resources owned by foreign multinationals, with little of the wealth 'trickling down to ordinary people. Industries based on these abundant natural resources could be developed to solve problems affecting the populations of developing countries. To alleviate poverty, they must sponsor young engineers' creative innovation and help boost the economies of countries they lie in and surrounding areas.

High technology companies can employ about 21 000 people or even more, like the 44 000 people who work for Rolls Royce and its programs, approximately 2% of Botswana's population. Simple efforts such as developing systems that enable fluid networking between innovative youth, potential sponsors and participants in proposed projects could be a good step. Exposure to different technologies is critical in accelerating innovation. If young scientists and engineers are introduced early to the latest technological and scientific developments, they may get acquainted with different technologies and, in some instances, even offer ways of improving them. In fact, this may result in a catch-up effect where developing countries or companies skip other levels of investment.

The key message communicated by this work is that engineers and other individuals should change their way of thinking and adopt ways to understand how other people's ideas work and see where they could fit in to complement their efforts or seek to improve them, resulting in the catch-up effect. Instead of replicating such efforts, looking first to being employed, or even refusing to help with crucial knowledge or other elements, other engineers' projects and ideas would succeed. Based on the illustration of a vending machine, it can be observed that technology in any of the engineering fields can never exist in isolation from other disciplines. This is because the skills involved in any technology are generally interdisciplinary. In that regard, it is suggested that the LF strategy or concept is one of the ideologies that could be implemented by most African universities in partnership with industry and government. The LF provides a paradigm shift to industry-partnered, interdisciplinary, real-world problem-solving in engineering education. The LF environment has a great potential to produce well-rounded graduates who can use technical and non-technical skills to solve African problems and be entrepreneurial and innovative to foster economic growth.

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