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A Results-Driven Curriculum for Engineering Education

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ABSTRACT

The field of engineering education faces an ongoing challenge of effectively preparing students for the demands of the rapidly evolving technological landscape. Traditional engineering curricula often focus more on theoretical knowledge rather than practical application and outcomes. As a result, engineering graduates are not equipped with the necessary skills to excel in industry, leading to a gap between industry requirements and graduate competencies. To bridge this gap, a results-driven curriculum for engineering education has been proposed to provide students with the knowledge, skills, and abilities required to succeed in industry. To address the question, "Where do most curriculum programs fall short?" It is noted that curriculum programs focus on delivering content rather than delivering experiences that support and enable change in teaching and learning. When curriculum design is driven by content, it ends up with numerous blurred boundaries regarding the scope, audience, and the applicability of what is contained in the curriculum. Consequently, the curriculum may result in education that falls short in producing graduates required by current and future markets and industry. In an e-learning and distance education environment, a curriculum might look well designed and meet all the set criteria, but it might ultimately match the wrong objectives. The result of this mismatch is that students after completing the curriculum depart with a lot of information in their heads but with no practical skills that they can implement in the workplace. This indicates that the graduate attributes required by Engineering Council of South Africa (ECSA) and industry were not attained by the student at completion of the enrolled curriculum. The research adopts a qualitative case study approach to explore and explain the steps, activities, and tools that can be used to design a results driven and engineering-focused curriculum solution, that has a clear goal tied to well-articulated pedagogy strategy.

Keywords: Curriculum, graduate attributes, engineering education, industry.

1. INTRODUCTION

Curriculum design in engineering education is a complex process involving the coordination of multiple interdependent components. A well-designed and effective engineering curriculum will develop, and nurture critical skills needed to achieve specific graduate attributes through a combination of learning activities and experiences (Zupan et al., 2023). However, the success of curriculum design is frequently uncertain, due to the absence of frameworks applicable for producing targeted specific graduate attributes. Given the significance of these outcomes, relying on trial and error is not a viable option. Fortunately, the process of developing an effective learning solution or curriculum is more attainable than perceived. Engineering education plays a crucial role in shaping the future of technological advancements and innovation (Zupan et al., 2023). It equips students with the knowledge and skills necessary to tackle complex engineering challenges and contribute to society. However, there has been a growing concern that traditional engineering curricula often fall short in meeting the evolving needs of the industry (Liao et al., 2023). While the engineering curriculum excels in imparting theoretical knowledge, it may fail to provide students with the practical skills and competencies required to succeed in their careers. This discrepancy between academic training and industry demands, has highlighted the need for a results-driven curriculum for engineering education. A results-driven curriculum places emphasis on outcomes and aims to bridge the gap between academia and industry. Rather than solely focusing on theoretical concepts. This curriculum approach prioritizes practical application, problem-solving, critical thinking, and effective communication (Devies et al., 2022). By aligning the curriculum with the skills and competencies demanded by industry professionals, the objective is to produce graduates who are better prepared to meet the challenges of the engineering field. This alignment is an important attribute of technology-focused education in the context of the Fourth Industrial Revolution (4IR), particularly for the universities of technology. The primary objective of a results-driven curriculum is to equip students with the necessary tools and experiences to excel in their careers. This entails providing them with opportunities to work on real-world projects, gain hands-on experience with cutting-edge technologies, and develop a comprehensive portfolio of work that demonstrates their proficiency in various engineering domains (Lv, 2023). By integrating practical experiences into the curriculum, students can enhance their problem-solving abilities, learn to adapt to different contexts, and effectively collaborate within multidisciplinary teams.

The development and implementation of a results-driven curriculum require close collaboration between academia and industry. It necessitates identifying the specific competencies and skills that employers seek in engineering graduates. Partnerships with industry professionals can help shape the curriculum, ensuring its alignment with industry requirements and current trends. Additionally, a feedback loop needs to be established to continuously assess and improve the effectiveness of the curriculum, ensuring that it remains relevant and up to date. A notable contribution to the field is the study by Xie, Zhang, and Yang (2019), which presents a competency-based curriculum model tailored for engineering education. Their approach focuses on equipping students with clearly defined engineering skills, allowing for the assessment of proficiency through measurable learning outcomes seeking to help with bridging the gap between academic preparation and industry demands and ultimately supporting efforts to better align engineering education with industry expectations (Zaki et al., 2019).

2. LITERATURE REVIEW

Engineering education plays a pivotal role in preparing students to meet the challenges of an evolving technological landscape. To attain efficiency in student preparation, Ditta and Bham (2020) postulate that it is a curricular cycle that involves development through needs assessment, design, and implementation phases. After this, outcomes are reviewed and evaluated against the original needs assessment. Needs change with societal expectations. The emphasis on different aspects varies depending on the perceived needs of the participants' and teachers' (Sethi & Khan, 2020). The dynamic curriculum requires change and resource management. These postulates are an apparent call to close the gap between Teaching and Learning programs and the industry requirements, and thus, the call and demand for a results-driven curriculum (Peterson et al., 2022). The mission of engineering technology education is to produce technologists to work with current technology. Therefore, engineering curricula must be a combination of applied engineering theory and hands-on instruction. Courses on mechanical drawing and design of engineering equipment must be core in the instruction of engineering technologists (Van Bossuyt et al., 2019). Engineering design is a linear and morphological process that requires a hands-on approach to instruction, application of design thinking in curriculum development is applied.

It is mission-critical for engineering technology instruction to emphasize more synthesis as opposed to analysis, that is, course content must include design thinking-related courses rather than scientific analysis and mathematical modeling (Van Bossuyt et al., 2019). In a study conducted by Singh et al. (2019), the authors proposed a framework for a results-driven curriculum for engineering education. The framework was based on three principles: (1) ensuring that the curriculum is relevant to industry needs, (2) using outcome-based education to measure student learning outcomes, and (3) incorporating active learning strategies in the curriculum. The authors argued that a results-driven curriculum would better prepare students for the workforce and provide them with the necessary skills to succeed. In a different study conducted by Almazan-Lazaro et al. (2018), the authors investigated the effectiveness of a problem-based learning approach in engineering education. The study found that students who were taught using a problem-based learning approach had a better understanding of the subject matter and were better able to apply their knowledge to real-world problems. This suggests that results driven curriculum strategies can lead to better learning outcomes for engineering students. While some scholars, such as Douglas et al. (2012), question the utility of problem-solving approaches like the design thinking paradigm due to their perceived linear structure, other researchers present a contrasting perspective. Pusca et al. (2018) argue that both the existing literature and experiential insights from fieldwork support the effectiveness of foundational problem-solving methods in addressing complex challenges. This aligns with Bloom (1956) conceptualization of a basic problem-solving strategy, which progresses through these distinct stages: initial problem recognition, problem definition, and final evaluation or verification. This approach is inherently iterative and shares methodological similarities with the design thinking framework.

A results-driven curriculum that is relevant to industry needs, grounded in outcome-based education and incorporated active learning strategies can better equip engineering students for the workforce and provide them with the necessary skills to succeed. The studies reviewed support and emphasized that engineering education curricula must employ engineering design because it is a linear and morphological process that requires instructional approaches that prioritize hands-on experiential learning.

3. RESEARCH METHOD

This research aims to develop, explain and evaluate a results-driven curriculum for engineering education with a specific focus on enhancing students' learning outcomes and performance. To achieve this, the study adopts a comparative research design, combining both quantitative and qualitative methods for a robust analysis of curriculum effectiveness. All research procedures adhere to the ethical guidelines stipulated by the university. Informed consent was obtained from all participants, and measures were taken to ensure the privacy, anonymity, and confidentiality of participants throughout the research process.

Research Design.

This study employs comparative research design, comparing the results-driven curriculum with traditional teaching methods in engineering education. The design allows for a systematic examination of the effectiveness of the curriculum and facilitates evidence-based decision-making. The research adopts a comparative design to evaluate the effectiveness of the proposed results-driven curriculum relative to traditional engineering teaching methods. This design enables systematic analysis of the impact on student performance and engagement and supports evidence-based conclusions.
Quantitative data were collected through assessments, performance scores, and student feedback surveys, while qualitative data were gathered through observations, and reflective journals. To enhance the validity and depth of the findings, the study applied data triangulation, drawing on three main sources:

(i) Document analysis and archival records, to establish the status of teaching and learning in engineering education.

(ii) Field notes and classroom observations, capturing experiential and contextual insights into instructional practices.
(iii) Analysis of teaching and learning system design, with particular focus on the application of Design Thinking and the implementation of a results-driven curriculum aimed at improving student performance.
This triangulation allows for a comprehensive understanding of the outcomes and experiences associated with each teaching approach.

As a practical example of the curriculum, the study integrates artificial intelligence (AI), robotics, and digital game-based learning into instructional activities. Teaching tools included Lego robotics kits, foundational machine learning concepts, and programming languages such as C++ and Python. These tools were selected to foster competencies in engineering equipment design, automation, and innovation, preparing students for engagement with Fourth Industrial Revolution (4IR) technologies.

Sample Selection

The sample for this research consists of engineering students from all departments within the School of Engineering. A stratified random sampling technique was utilized to ensure a representative sample of students across different engineering disciplines, academic levels, and departments (i.e. Industrial, Mechanical, Chemical, Civil, and Electrical Engineering).

Data Collection

a) Pre-assessment: Prior to the intervention, students' baseline knowledge and skills were assessed using a pre-designed test, which served as a benchmark for later comparison referred to as the "AS IS" state.
b) Curriculum Implementation: The results-driven curriculum was implemented for the experimental group, while the control group continued with the traditional teaching methods.
c) Post-assessment: After the intervention, a post-assessment was conducted to measure the student's learning outcomes and performance. The same test used in the pre-assessment will be administered to both groups to ensure consistency.
d) Surveys and observations: Additional data were collected through surveys and classroom observations to capture qualitative insights into students' perceptions, learning experiences, and satisfaction with the results-driven curriculum.

Data Analysis

Quantitative data was analyzed using appropriate statistical techniques and hypothesis testing, to determine whether significant differences existed in learning outcomes between the experimental and control groups. Qualitative data from surveys and observations were thematically analyzed to identify recurring patterns and themes relevant to the teaching approach.

Limitations

This study acknowledges several limitations. There is a potential for sampling bias, which may affect the representativeness of the findings. The generalizability of the results to other engineering or educational contexts is also limited, as the investigation focused on a specific institutional and disciplinary setting. In addition, the relatively short duration of the intervention may not adequately reflect long-term impacts.

The research employed a case study methodology informed by a well-defined theoretical framework, incorporating both desktop analysis and observational techniques. Although this method enabled a detailed investigation within a particular setting, it may restrict the extent to which the findings can be applied to other educational or engineering environments. Furthermore, the use of pre-existing field notes and archival documents, rather than direct data collection, may have limited the richness and immediacy of the insights into current teaching and learning practices.

4. DISCUSSION

Higher Education has been subject to many changes and developments imposed both by governing bodies such as governments, and ECSA and by changing public and industry expectations. In Engineering Education (EE), there have been additional changes reflecting a challenge in the demands for graduate attributes and in the roles, responsibilities, and public perceptions of the profession.
Scandals such as faulty bridges and failure of railway operations, including shortages in electricity production have not only undermined public and industry confidence in the way that the engineering profession and universities train and produce competent professionals. This change in perception has led also to an increased emphasis on accountability, quality control, and self-regulation. All these factors must be considered in developing a result-driven engineering curriculum.
In developing a results-driven curriculum the suitability of the design thinking paradigm as an adaptive use of engineering design methods and tools to solve complex problems was demonstrated by Pusca et al. (2018) through empirical research conducted in the context of curriculum development. Findings from Pusca et al. (2018) and Swamy et al. (2024) indicate that the adaptive application of engineering tools can effectively address key challenges in curriculum development, particularly in the design and implementation of courses that align with outcome-based education objectives.
Developing a results driven curriculum begins with a schematic of the design paradigm as an engineering design process (Manzoor et al., 2017). The process starts with the need for identification and formulation of the problem, including any associated constraints (Pusca et al., 2018). This first step is very important, since a well-formulated problem is necessary to find the desired solution. Once the solution is established, it is then implemented. Note that the solution can be found from research of solutions for similar cases in the past and from the use of creativity to generate new ideas (see Fig 1).

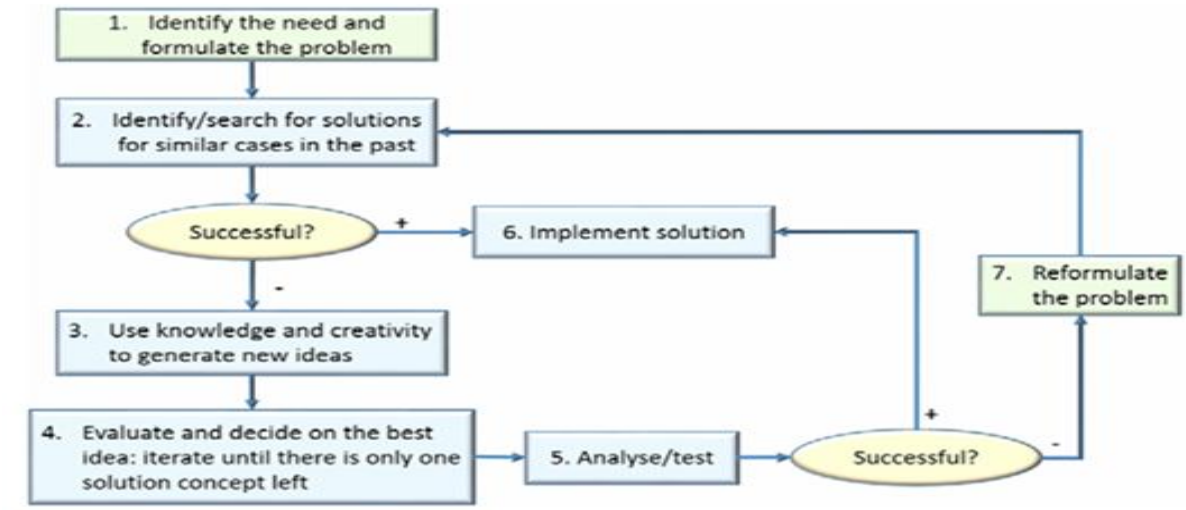

Fig 1: A Design Thinking-based Engineering Design Process (Pusca et al., 2018).

In case a suitable solution is not established from the search for a solution from similar cases in the past, using a design thinking-based engineering design process, a design thinking paradigm for results-driven curriculum development is employed (Fig 2). Pusca et al. (2018) support the suitability of the design thinking paradigm as an adaptive use of engineering design methods and tools to solve complex problems, and this was demonstrated through empirical research conducted in the context of curriculum development to provide innovation in curriculum development. Authors also indicate that design thinking should be thought of as a form of experimental thinking that is solution focused and may be implemented to produce creative solutions to complex problems, as mentioned by Taubman (2010).

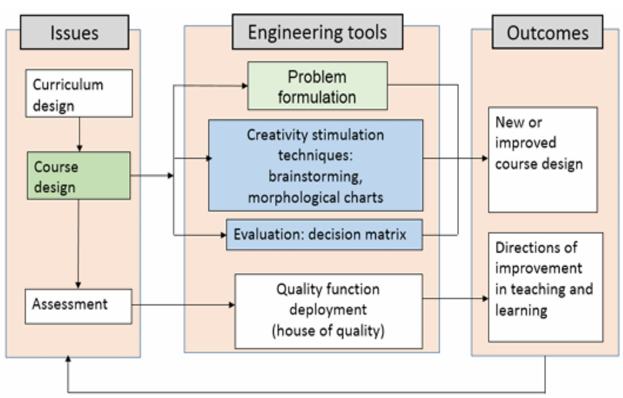

Fig 2: Design Thinking for Adaptive Results-Driven Curriculum (Pusca et al., 2018)

Application of the design thinking for adaptive results driven curriculum culminates in the development of a teaching and learning method process that integrates adaptive learning and game-based learning (GBL) in the execution of a results driven curriculum for engineering education (Fig 3). The method process applies concepts of adaptive learning, scaffolding and laddering in the teaching and learning process execution.
The process begins with capturing the learning status quo and then designing future and improved settings based on learning needs, complexity of the status quo and the desired outcomes. Design thinking enables the conversion of the status quo to an improved desired future state, through the design, development, and application of an Adaptive Results Driven Curriculum.

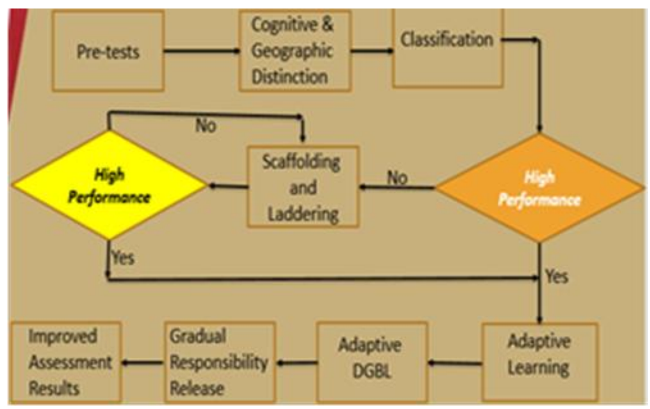

Fig 3: Results Driven Curriculum Teaching and Learning Method process (by author)

The Teaching and Learning (T&L) method process begins with establishing the subject matter competency's status quo, through a pre-test for all participants. The results of the test are used to group students based on their performance in the test. The groups are established using cognitive description and they are grouped according to the following performance percentages: A-group (100-80%), B-group (79-70%), C-group (69-50%), and D-group (49-0%). Participants in group A are denoted as a high-performance group and the group is sent through adaptive learning (AL), then digital GBL, followed by a gradual release of responsibility (GRR), and then student success is achieved. In adaptive learning for group A, problem-solving becomes progressively complex. Then a good performance in adaptive learning leads to a digital game-based learning level, in which students are given a database of practical application problems, such as the Beer game and The Fresh Connection (TFC), in a digital setting. Success in the DGBL level leads to student autonomy level, i.e., GRR. In GRR students learn to self-direct and control their learning path, in this stage, DGBL and AL are integrated into Adaptive DGBL (ADGBL). At this level, participants experience challenges with a high level of complexity, based on Bloom Taxonomy. Performance targets are set to allow participants in group A to pace themselves towards achieving the desired results. Groups B, C, and D are placed in an iterative process of the T&L method process. Participants are placed in a continuous assessment and evaluation program, in which an excellent performance (80%) results in a promotion to the next level, that is, for group B they are promoted to A and C to B, D to C. Group is treated differently at the beginning since the comprehension is very low and they are failing the module. The group is placed through a laddering program. Laddering refers to a program in which the subject matter is broken into simpler and smaller parts in the T&L process. Participants are continuously engaged through laddering and scaffolding, and the complexity of the problems is increased as they improve their assessment performance. Participants are placed in an iterative program until their performance in assessments is 80% and above, then they are promoted to the next level or group. The program continues until the learning and teaching period ends, that is, the end of a semester or a year. The program manifests a personalized program for groups and individuals.

5. RESULTS

The teaching and learning method process enables the achievement of the goals and objectives of a results-driven design, which is student success and student autonomy in an Online Distance Electronic Learning (ODeL) environment. Student success implies an increase in throughput, an improvement in student test outcomes, and an increase in student retention. The teaching program is instructionally designed to develop a personalized and differentiated learning process for students, through breaking down lessons into lower and basic components, for struggling learners. The program progressively improves lessons to a complex high level and challenging activities for excelling students, and it has proved to have produced positive results. First, the struggling student's group (D) is reduced gradually, and the excelling student's group (A) is increased. Second, the two homogenous groups of good performance and struggling learners (Fig 4), gradually disappear and they are replaced by numerous and smaller groups of learners performing above 50% (Fig 5 and 6). Towards the end of the first round of the study, i.e. 2017/2018, it becomes apparent that the group of excelling students (A) increases and that of struggling students (D) decreases significantly. It is also clear that more learners have improved their performance above 50% and a large group is in the category of excellent-performing students (group A). A result-driven curriculum execution T&L method process developed has improved student performance gradually and increased the number of excelling students. In general, student success rates have increased, and performance improved for many learners by about +25%.Some of the key aspects of learning emanating from the implementation of a results-driven curriculum are:

•Learning can be seen to occur in four domains (eg. Bloom et al, 1956 and others): cognitive (knowledge and intellectual skills), affective (feelings and attitudes), interpersonal (behavior and relationships with others), and psychomotor (physical skills)

•Individuals can be seen to have different learning styles so courses should be designed with a variety of learning (and teaching) methods

•Learners need to be treated as people and there should be opportunities for them to make contributions that are valued by teachers

• Effective learning is active – people learn best when they are engaged in an active process and learning must be relevant to learners' own experiences and needs and to be set within a clear context or framework. Relevance applies at a variety of levels: to the overall structure of the course or subject or to the use of technology

•Learning outcomes or objectives helps learners to learn because they define what the learner must do, the outcomes should be explicit and clearly linked to delivery and assessment. Effective learning needs to be done in a safe environment. Learning is not always easy, and learners must feel comfortable and able to make mistakes. Feedback should be constructive and timely.

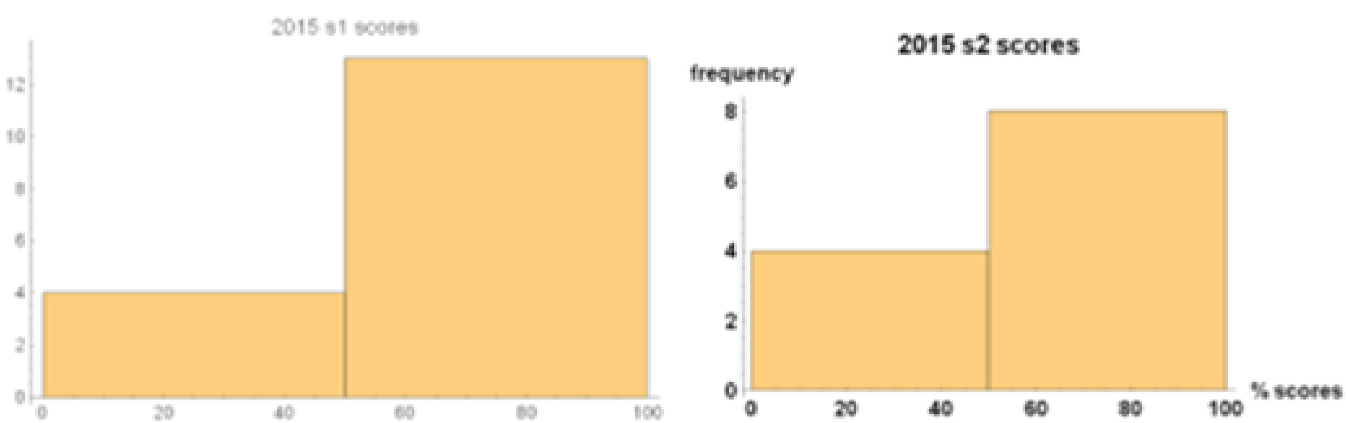

Fig 4: Assessment Performance Results for 2015

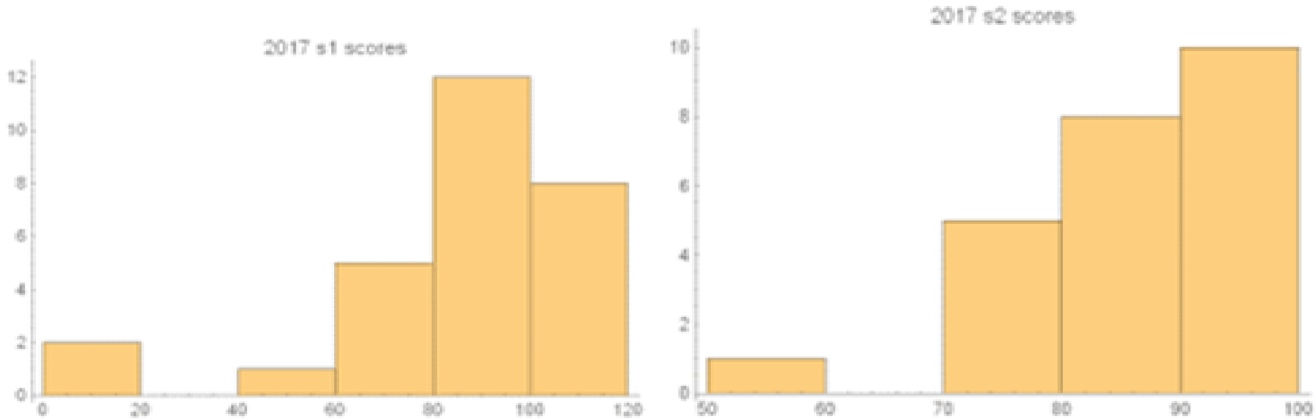

Fig 5: Assessment Performance Results for 2017

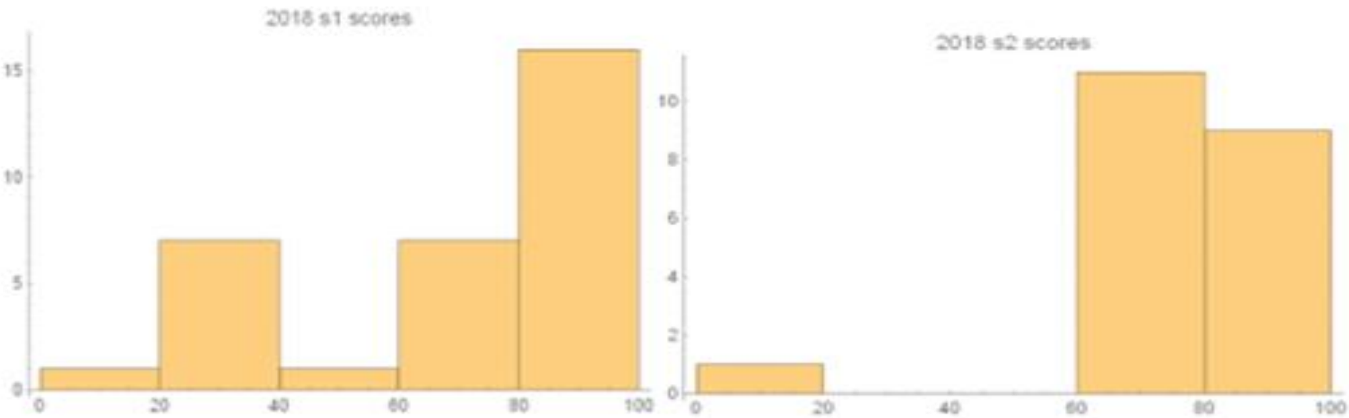

Fig 6: Assessment Performance Results for 2018

6. CONCLUSION AND RECOMMENDATIONS

One of the most influential approaches to engineering education has been problem-based learning (PBL) developed by Barrows, Harden, and others. PBL aims to stimulate students to observe, think, define, study, analyze, synthesize, and evaluate a problem. The problems or cases are written to simulate real-life engineering problems which are multidimensional and encourage students to think as they would in real-life industry situations. Digital game-based learning and Robotics and AI strategies have so far produced good results and thus should be part of EE programs in Universities of Technology.Therefore, the results-driven curriculum execution process of teaching and learning is different from the common and general method, because it focuses on helping students to develop a higher level of comprehension of subject matter content. Thus, it remedies T&L problems and responds to the questions, where do most curriculum programs fall short? Therefore, the innovation implemented confirms that it is no longer possible to treat all students in the proliferating range of e-learning users with very different prior knowledge, backgrounds, learning styles, interests, and preferences, with the one-size-fits-all approach.

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