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Engaging African engineering students with problem-based learning by using the disassembly–assembly technique

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Abstract
Problem-based learning identifies problems in ways that are conducive to student learning and emphasizes problem-solving, critical thinking and collaborative skills. These three aspects are core to disassembly–assembly techniques used in higher education where students are required to engage with visual, auditory and kinesthetic learning within a laboratory environment. The purpose of this article is to describe a disassembly–assembly technique used in a compulsory engineering module and identify how many African engineering students can successfully create a problem (disassemble a two-stroke motor) and then correctly solve the problem (assemble the two-stroke motor back to a working condition). A longitudinal study involving quantitative data is used with descriptive statistics. Results indicate, that on average, 85.5% of African engineering students can successfully engage with the disassembly–assembly technique. A possible recommendation is to encourage more academics to make use of the disassembly-assembly technique with regard to engineering systems, equipment or machinery.

Keywords
Dissection, skills, learning styles, active, visual, auditory, kinesthetic

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Introduction

"It is better to create than to learn! Creating is the essence of life".[1] These words, by Julius Caesar, a Roman politician, general, and notable author of Latin prose, well illustrate the importance of creating, rather than learning. Creating requires students to engage with active learning, where visual, auditory and kinesthetic learners benefit. Visual learners remember best what they see. Auditory learners remember best what they hear. Kinesthetic learners remember best what they physically do. Felder and Silverman[2] referred to these types of learners when discussing various learning styles of students in engineering education, but included sensing or intuitive and global or sequential learners in their discussion.

In engineering today, one tends to find many students who are both visual and kinesthetic learners.[3–7] Academics must therefore include more experimentation in their teaching practice, where engineering students need to create a problem that must be solved using visual and kinesthetic learning. The disassembly–assembly technique is one strategy that may be used to accomplish this, where problem-based learning (PBL) is encouraged.

However, it is recognized that some students struggle with PBL. This has been documented in electrical engineering,[8] in geography,[9] in library and information services,[10] in mathematics,[11] in mechanical engineering,[12] in nursing,[13] and in science.[14] This is in contrast to other literature that suggests that students enjoy PBL, often preferring it to traditional teaching and learning methods.[15] The research question thus arises "What percentage of African engineering students can successfully engage with PBL, with specific reference to the disassembly-assembly technique?"

It must be emphasized that the disassembly, or dissection technique, has been used for many years in education to help students fuse theory and practice. However, the purpose of this article is primarily to emphasize if African engineering students can successfully engage with it, thereby reinforcing or undermining its application within the African context. Research can either reinforce knowledge or uncover new information, and it is important to communicate either outcome to others.[16] This is especially so within the South African higher educational landscape today, where students are demanding the decolonization of the curriculum while government is mandating the internationalization of the curriculum. Both need to be accommodated in the curriculum, which also needs to identify the learning activities and assessment strategies that may either include, or exclude, the extensive use of PBL. The link between PBL and the disassembly–assembly technique is firstly established. The context of the study is then explained, along with a detailed description of the technique. Academic results of this technique are presented, followed by the conclusions.

PBL and the disassembly–assembly technique

PBL is often found in capstone modules where fundamental problem-solving skills need to be assessed.[17] These skills include being able to identify and understand a problem and then to develop potential solutions.[18,19] Rational problem-solving skills further include evaluating and choosing the best solution.[20] These skills are encapsulated in the graduate attributes defined by the International Engineering Alliance[21] to which the Engineering Council of South Africa is a signatory. This highlights that fundamental problem-solving skills are generic to all engineering disciplines, and is fundamental to the disassembly–assembly technique of engineering systems, equipment or machinery. Take, for example, a two-stroke motor. When students disassemble a two-stroke motor into its various parts or sections, they create a problem in that the motor no longer works. Students now need to solve the problem by assembling it back to a working condition. No spare parts may remain after the motor has been reassembled. If parts remain, or if the reassembled motor does not work, then students would have to apply the identify, understand, solution, and evaluation (iUSE) principle noted by Swart and Toolo.[17] They would now need to isolate or *identify* the faulty section by applying their knowledge or *understanding* of each section. They would then need to provide a *solution* and *evaluate* its effectiveness. This iUSE principle would definitely require critical thinking.

PBL provides students with the setting to exercise critical thinking in solving problems while gaining new theoretical knowledge.[22] Critical thinking may be credited to the work of John Dewey who avidly advocated the role of reflection in education.[23] Dewey promoted the concept of experiential education which focuses on critical thinking rather than memorization. Over the years, critical thinking has become intertwined with reflective practice, as the one cannot exist without the other. Critical thinking involves the logical progression from mere knowledge and understanding to the highest levels of synthesis and evaluation, as defined by Bloom's Taxonomy.[24,25] Critical thinking is especially important when it comes to fault-finding techniques. For example, when a two-stroke motor is assembled, it must work. If it does not, then students need to retrace their steps and use their newly acquired knowledge and understanding of each section that has been combined (synthesized) to evaluate the correct operation of each section, thereby isolating the faulty section that needs attention.

Hmelo-Silver[26] notes that PBL involves students working together, in groups, in order to "learn what they need to know in order to solve a problem." Working collaboratively together in groups is fundamental to engineering, where major projects often require a number of skilled personnel, including chemical, civil, electrical, industrial, and mechanical engineers. These engineers also need effective communication skills, as they need to converse during project meetings and site visits in order to determine the progress of the project and what challenges need to be overcome. Group work is also one of 12 graduate attributes defined by the International Engineering Alliance,[21] which students need to demonstrate through their educational career at university and within the disassembly–assemble technique. Consider again, the case of assembling a two-stroke motor. Different parts may require two pairs of hands to be loosened or fastened into position, depending on the weight or position of the part. Here, effective communications skills would also be vital as students need to determine which part must next be connected, which position should it be set in and how tight relevant bolts or nuts need to be made.

When PBL involves the application of knowledge to a practical task, students become engaged in the task and in the learning process itself, linking experience and observation to contextualization and experimentation.[27] This may be achieved by using the disassembly–assembly technique that has been effectively used in pedagogy and andragogy. For example, school children have demonstrated the ability to disassemble and rebuilt mini-robots to achieve various goals.[28] The repetitive assembling and disassembling of robots have been shown to enhance learner's competency to complete the task in shorter periods of time.[29] As an activity in a higher educational laboratory, students perform disassembly–assembly of a small industrial gas turbine.[30] The fusing of theory and practice in this regard has proved very beneficial, as students confirm that they understand more easily the subject being taught during the lectures as they engage in active learning. This is achieved through observation (visual learning), communication (auditory learning), and experimentation (kinesthetic learning). Students physically see the various part and components, describing their structure or location to fellow students while tangibly interacting (e.g. remove, replace, fasten, loosen, turn, push, or pull) with various parts and components within a laboratory environment. Any engineering qualification should allow students to experience being an engineer, by introducing PBL, where theory and practice can be fused to ensure real-world solutions.[31]

Context of the study

Professional Practice I (better known as FIAP 172 by students and academics) is a compulsory module in the Bachelors Engineering qualification (termed the BEng degree) for all engineering students at the North West University (NWU) in South Africa. It is offered over the course of an entire year, with the syllabus split across two semesters which are roughly 14 weeks in duration. Students have to accumulate 628 credits in this four-year degree, where the first year comprises 156 credits, the second year 180 credits, the third year 156 credits, and the final year 136 credits. Engineering students obtain 24 credits when they successfully complete FIAP 172, indicating that they devoted 240 notional hours to this module.

The aim of FIAP 172 is to give engineering students the opportunity to develop management skills as it involves much group work where imaginary companies are formed with the goal of design and constructing working models of projects for real clients. Some of these projects include a working hovercraft, a pet-dipping station, and a recycling machine, all developed by students to suit the needs of real clients. The structure of the module is shown in Table 1.

Registered African engineering students are required to complete a practical workshop induction program before engaging with the aim of the module. This induction is held over a period of one week, where three different practical sessions of 8 h each must be attended. This induction covers aspects relating to safety,

Table 1. Module structure of FIAP 172.

Event	Time
Registration for the module	February
Induction program (including the disassembly–assembly technique)	March
• List of projects given to student groups (six students per group)	April
• Students need to select three projects and prepare a PowerPoint presentation on what would be required for each one	
• Based on the presentations, the facilitator assigns the project which has been well presented by the students (students have demonstrated a keen understanding of what is required)	
• A concept design of the project is then required	
Detailed designs of the project are required using computer aided design (CAD) software	May
Examinations are scheduled with the mid-term break	June and July
• A detailed budget needs to be submitted	August
• Construction of the project starts	
Project needs to be completed, tested and evaluated according to the original requirements	September
• Students exhibit their projects to the Industry partners	October
• Students submit a final reflective report on their year's work	
Final grades uploaded to the university computer system	November

electrical motor operations, welding, fitter and turning practice, and general electrical principles. This empowers students with the required theoretical knowledge which they will need to apply when engaging with the aim of the module. This aligns with research by Biggs[32] who states that quantitative stages of learning (knowledge or theory) occur first, followed by qualitative stages of learning (practice). It also follows the learning cycle of Kolb[27] (concrete experience, reflective observation, abstract conceptualization, and active experimentation) and the alternative framework for developing performance objectives devised by Gagné[33] (verbal information, intellectual skills, cognitive strategies, motor skills, and attitudes). Students are rotated among the three practical sessions, as the workshops are not large enough to accommodate all the registered students at the same time. An indemnity form is furthermore signed by the students thereby releasing the university from any legal action that may arise due to student injury.

A list of possible projects from Industry is then shared with groups made up of six students each, who need to identify a possible one and prepare a PowerPoint presentation on what they think would be required to successfully complete the project. The facilitator then awards a specific project to a group based on their level of understanding of that project as demonstrated in their presentation. A concept design, detailed design, and detailed budget must then be submitted. Students physically work on their project for about two months, with a final test and evaluation at the end of September. An exhibition in October makes their completed project public knowledge to all Industry partners that are present. Regular communication between the facilitator and student groups occurs via the institutions learning management system, which is built on SAKAI (a free, community source, educational software platform).[34]

The induction program includes a practical workshop focusing on the disassembly–assembly of a two-stroke motor. This practical workshop starts with a brief lecture on the differences between two-stroke and four-stroke motors, along with specific safety guidelines. Safety instruction provides information about the hazard, instructions for avoiding harm, and a motivational rationale for obeying those instructions.[35] The principle of operation of two-stroke motors is then explained, with emphasis being placed on its various sections.

Once the lecture is complete, then students are given a workshop manual of the two-stroke motor (a Hoffmann power air-cooled petrol engine[36]). This is in-line with the disassembly–assembly technique applied by LEGO® Education who provides full instructions to students which encourages discussion and problem-solving during both the build and programming stages of the activity.[37] Students need to follow the workshop manual in disassembling the motor, placing each of its parts in an orderly fashion on a table. This creates a problem in that the motor no longer operates correctly. Once the entire motor has been disassembled, then students need to assemble it again by referring to the workshop manual. No parts are allowed to remain and the motor must work correctly when completed.

If spare parts exist after the assembly, or the motor does not work, then students must engage with fault-finding techniques to isolate the problem (faulty section). Fault-finding techniques can be time consuming and relies heavily on the acquired skills of individuals to diagnose symptoms and determine the root cause of the problem.[38] This may entail removing many of the parts again, to determine where the students went wrong. Critical thinking is involved, as students need to recall the purpose (requiring understanding) of each part of the motor, evaluating its operation and judging whether it is faulty or not. Teamwork and communication are also essential, as students need to discuss the steps they are taking and help each other loosen bolts or hold parts in place as bolts are fastened. Figure 1 shows two female students disassembling the two-stroke motor while Figure 2 shows two male students assembling one, with the relevant parts in the foreground. Teamwork is evident in both these figures, as is visual learning (students observing the structure and location of the various parts), auditory learning (students communicating with each other as to which part should next be removed or connected) and kinesthetic learning (students physically touching the various parts by loosening and tightening them according to a logical procedure).

Research methodology

A longitudinal study involving quantitative data is used. Longitudinal studies are defined as studies in which the outcome variable is repeatedly measured.[39] In this study, the outcome variable is the percentage of African engineering

Figure 1. Female students disassembling the two-stroke motor.

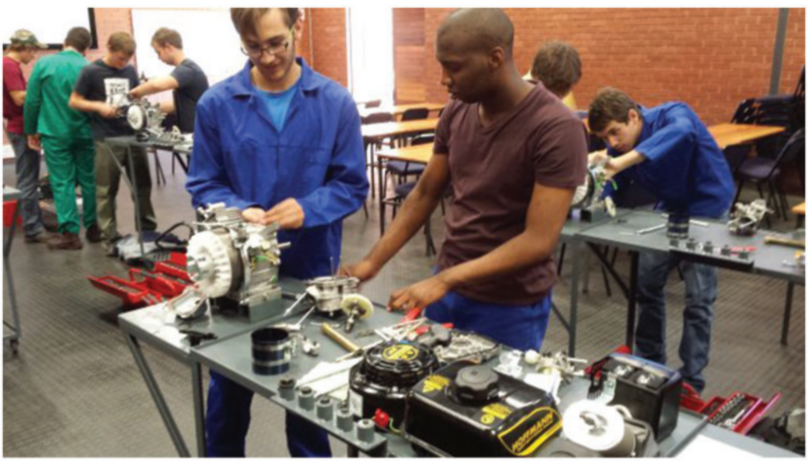

Figure 2. Male students assembling the two-stroke motor.

students that can successfully engage with PBL, with specific reference to the disassembly–assembly technique. This is done for a period of two years (2015–2016) by obtaining quantitative data for each year from a different group of African engineering students at the NWU in the North West province of South Africa. Each additional wave of data (or data from each successive year) from a longitudinal study increases the reliability and precision of measuring change and adds power to the results.[40] These African engineering students are first-year, or freshmen students, who may have never worked in an engineering laboratory before.

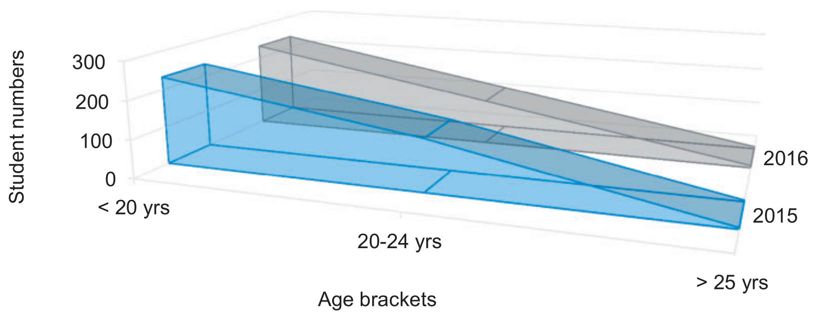

Figure 3. Student age brackets.

Descriptive statistics, rather than inferential statistics, are used as the results are interpreted with regard to specific engineering students enrolled at the NWU, located in Potchefstroom. Descriptive statistics include the student profile and the number of students who could successfully complete the disassembly–assembly technique. The target population involves all African engineering students enrolled for FIAP 172 during the three-year period ($n = 736$), thereby requiring no sampling technique.

The NWU Institutional Research Ethics Regulatory Committee granted an ethics approval certificate to the study early in 2016. This was after the application was completed and submitted in 2015. Permission was granted to use the demography and final grades of students from 2015 onwards, if no student names or numbers were released. All first-year African registered students completed an informed consent form, where voluntary participation was emphasized.

Academic results and student perceptions

Figure 3 presents the age brackets of the students enrolled for FIAP 172 for 2015 and 2016. The majority are less than 20 years of age, as they are freshmen engineering students who have just completed their secondary or high school career (average age for Grade 12 learners in South Africa is 18 years[41]). The total number of students who registered for 2015 was 373, while those who registered for 2016 were 363. Figure 4 indicates the number of female and male students who registered for FIAP 172, with their corresponding pass rates. The minority of students are female (1:5 ratio to males), which is one of the reasons why a global drive exists to encourage more women in engineering.[42] However, what is noteworthy is that a higher percentage of females (95.5% average) successfully completed the module as compared to male students (86.5%). This is in line with research that indicates that females outperform males in engineering.[43]

The home language profile of students registered for FIAP 172 is shown in Figure 5. These results show very little difference between the two groups of

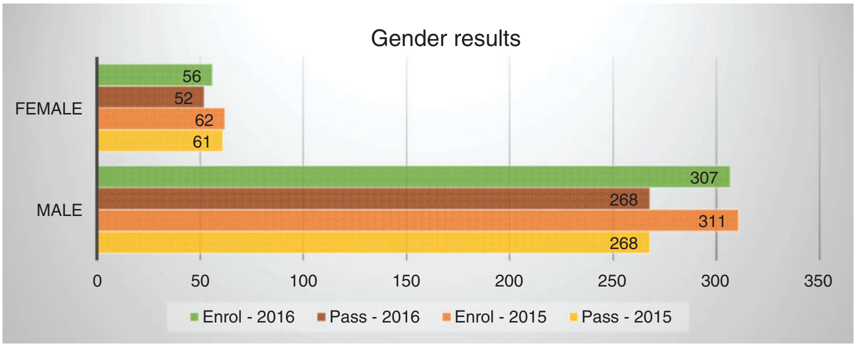

Figure 4. Gender results.

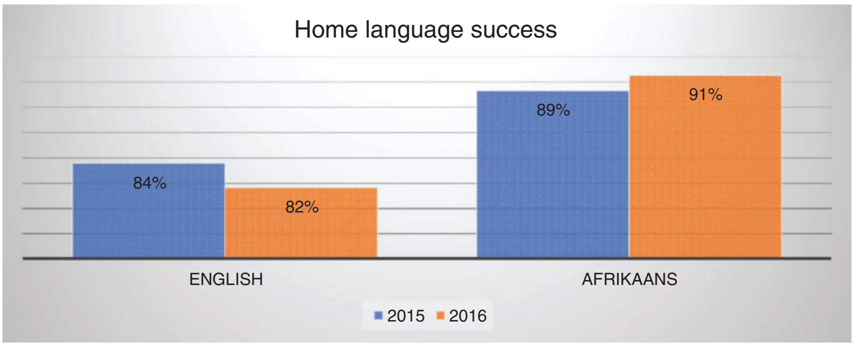

Figure 5. Home language results.

students, where both group's major home language was Afrikaans (indicative of the North West province in South Africa where the major languages spoken include Setswana, Afrikaans, and English[44]).

Figure 6 illustrates a bell-shaped curve showing the distribution of student final grades awarded in FIAP 172 during 2015 (solid black line) and 2016 (solid grey line). Each white dot within these lines represents a grouping of similar achieving students regarding their final grade. A number of white dots are visible in the black line close to 100%, while a lower number is visible in the grey line. This suggests that more students achieved a distinction in 2015 than in 2016. This may well be attributed to the raising of the standard within the module in 2016. The module is continually enhanced to meet the ever changing needs of students, industry, and society, which has similarly been done in other courses.[45,46]

The majority of students lie along the median (solid vertical line for 2015 and vertical dotted line for 2016) as indicated by the condensed number of white dots. The median is lower for 2016 (being 64.5%) as compared to 2015 (being 67.7%) due to the improvements made in the module to raise the standard of teaching and

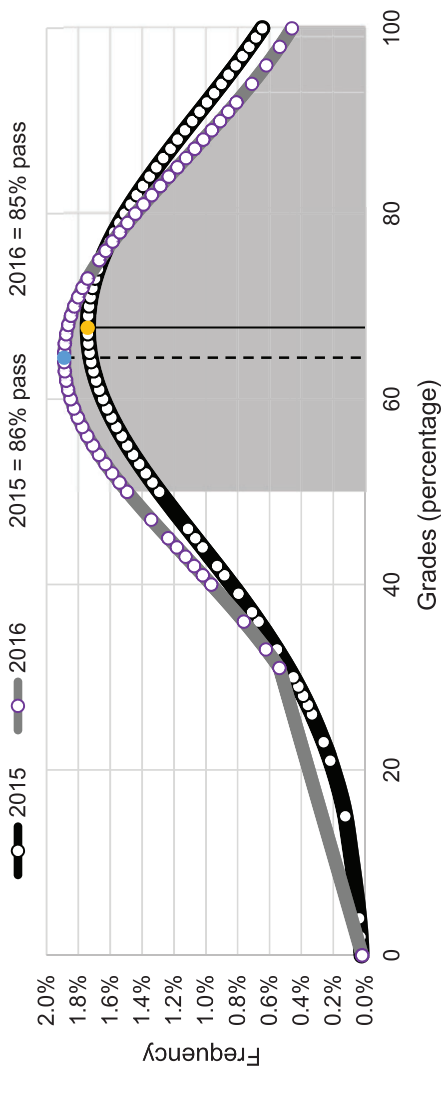

Figure 6. Bell curve showing the median for 2015 and 2016.

learning. Students need to lie within the grey-shaded area to successfully complete the module, which is above 50%. The majority of students lie in this area (average of 85.5%), which indicates that 14.5% of African engineering students cannot successfully engage with the disassembly–assembly technique, although they did attempt it. This further implies that these students struggle with PBL, which is fundamental to the disassembly–assembly technique, and is evident by the spread of white dots between the final grades of 20 and 50%.

Conclusions

The purpose of this article was to describe the disassembly–assembly technique used in a compulsory engineering module that assists African engineering students to acquire necessary problem-solving, critical thinking, and collaboration skills. This is done through the creation of a problem (disassemble a two-stroke motor into its main sections, thereby causing it to not work correctly) and then by solving the problem (assemble the two-stroke motor back to a working condition which requires critical thinking, teamwork, and communication).

Results indicate that a higher percentage of female students successfully complete the module as compared to male students. However, on average, only 85.5% of the registered students successfully completed the FIAP 172 module, indicating that 14.5% of African engineering students cannot successfully engage with the disassembly–assembly technique.

It is true that this study was limited to only two calendar years and to one module in engineering. Reviewing the achievements of first-year African engineering students over another two years would help to verify these results, providing further reliability of the results. Moreover, comparing this module's results to other engineering modules in Africa where a similar disassembly–assembly technique is used would help to provide inferential analysis.

It was noted in the introduction that some students from different fields struggle with PBL, which has been verified by this study. Future research could highlight reasons as to why these students struggle with PBL and what could be done to further assist them in overcoming their challenges. Another possible research approach would be to obtain student feedback on the disassembly–assembly technique as to whether it is challenging, beneficial, enjoyable, and relevant to the aim of the module.

A possible recommendation emanating from this research is to encourage more academics to make use of the disassembly–assembly technique in their teaching and learning process. This should especially be applied to the synthesis of systems, such as a telecommunication system, an air-conditioning system, a reverse osmosis system, and a hydrology or hydraulics engineering system.

One tends to find many engineering students who are visual and/or kinesthetic learners. The disassembly–assembly technique described in this article has provided these types of students with the opportunity to both see and feel (observation and experimentation according to Kolb) how a two-stroke motor is assembled. PBL has been encouraged among African engineering students who created a problem by disassembling a two-stroke motor into its various sections, and then solving the problem by re-assembling it back to its original working condition by using active learning where visual, auditory, and kinesthetic learners benefit.

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