Design and development of practical instruction for freshmen engineering students in a renewable energy course

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***Abstract*— Technical competence and problem solving skills are key graduate attributes that engineering students must develop, especially within a practical laboratory. A new specialized course in renewable energy was introduced at the beginning of 2014 at the Central University of Technology, with the main purpose of addressing this goal. The purpose of this research is to describe the design and development of relevant practical instruction which was introduced into one of the solar energy modules, termed Solar Energy Systems II. This module forms part of the curriculum of the new renewable energy course. The backward curriculum design method was applied in developing the practical instruction. Five learning outcomes were specified while three assessment strategies were selected, including oral presentations, written laboratory reports (headings include the experimental question, hypothesis, materials, procedure, observations, data, conclusion and reflections) and a final written class test. Two main pedagogical methods were used involving authentic learning and computer-based learning, while lectures, group work, videos and a learning management system were also used. A questionnaire was finally used to obtain student feedback on the practical instruction. Students indicated that the practical work was enjoyable (92%), relevant to the theory (83%), and a valuable learning experience (97%). This practical instruction has given freshmen engineering students the opportunity to demonstrate their acquisition of important graduate attributes that may help them to contribute to the socio-economic development of South Africa.**

Keywords*— *Solar energy, curriculum design, learning outcomes, graduate attributes

I. INTRODUCTION

"It is the weight, not numbers of experiments that is to be regarded". These words, by Isaac Newton, well indicate the importance of well-defined quality experiments. This is also true regarding experiments that are used in engineering education. Equipping freshmen engineering students with the needed skills and attributes to install and maintain solar energy systems requires tertiary institutions to offer specialized courses in renewable energy. The Department of Electrical, Electronic and Computer Engineering at the Central University of Technology (CUT) implemented a Higher Certificate in Renewable Energy Technologies (HCRET) in January 2014, which is the first undergraduate course in renewable energy approved by the South African Qualification Authority (SAQA).

SAQA prescribes a number of critical cross field outcomes which must be met by a specific educational programme, and which may be correlated to the exist level outcomes specified by the Engineering Council of South Africa (ECSA) for all engineering related programmes [1]. These exit level outcomes may in turn be correlated to the 12 graduate attributes specified by the International Engineering Alliance [2] in their "Graduate Attributes and Professional Competencies" document.

Subsequently, it must be stated that, engineering students must be helped to demonstrate the acquisition of these graduate attributes, especially if are to make a significant contribution to the socio-economic development of their communities and their country. However, research indicates that many seniors graduate from university without the ability to reason clearly or perform competently in analyzing complex, non-technical problems. Appropriate pedagogies must therefore be sought which may enable students to fuse theory with practice [3, 4], thereby enabling them to apply their engineering related knowledge to solve engineering related problems. One such pedagogy involves the use of educational technologies.

Educational Technology is defined as an array of tools that might prove helpful in advancing student learning [5]. In the context of this study, educational technology is defined as the use of both electronic equipment (hardware) and computer software in assisting engineering students to grasp fundamental solar energy principles applicable to photovoltaic (PV) modules. Practical instruction is therefore developed using this education technology in a laboratory environment, becoming an enabler for students to fuse their theory with practice, which is a fundamental requirement in any engineering curriculum [3, 4, 6-8].

The purpose of this paper is to describe the design and development of relevant practical instruction which was introduced into one of the solar energy modules, termed Solar Energy Systems II, which forms part of a new renewable energy course offered at CUT. The curriculum design process is firstly substantiated. Secondly, the context of the study is presented.

Lastly a few student perceptions regarding the practical instruction are then provided, followed by succinct conclusions.

II. CURRICULUM DESIGN

Three main curriculum design processes exist, namely the backward design, the forward design and the student-centered design. The aim of the backward design is to determine the learning objectives of the course and then to create methods of evaluation and assessment accordingly. The process starts with the learning outcomes which dictate what the student should be able to do, demonstrate or master in order to complete the course successfully [9]. The compilation of these learning outcomes is a collaborative effort involving various stakeholders [10]. These stakeholders may include official accreditation institutions, such as ECSA, academics and other industry leaders. The next step relates to developing evaluation methods in a way that test the learning outcomes effectively [11]. These methods must give the student the opportunity to demonstrate that he/she has mastered the learning outcomes. Pedagogy that supports the learning outcomes and the assessment strategies must be developed accordingly [12]. This pedagogy must set the right learning environment to enable the student to succeed. Thus, a syllabus is developed that supports the learning outcomes and which includes appropriate and relevant subject matter or content [13]. It is clear that learning outcomes are an integral part of the backward design process and it must be prioritized in order to support the rest of the process.

The forward design works in reverse as compared to the backward design, starting with the syllabus [14] and content; what do we want students to know? The syllabus and content is usually compiled by a number of key stakeholders, including ECSA, Industry and academia. Prescribed books, journal articles, e-books and audio-visual material may then be identified or selected by academics to cover the required content and syllabus. Pedagogical methods are chosen next, taking into account the diverse learning styles of the particular students. The pedagogical methods and syllabus are then used as guidelines to determine the assessment strategies. The last step in the forward design method is to formulate the learning outcomes.

The student-centered design focuses on the student's needs with assessment and pedagogical methods being developed accordingly [15]. The design follows a continuous circle of planning, assessment strategies and presentation. In the planning phase, course material is identified and achievable learning outcomes are set. Course material is developed with the aim of assisting the student in achieving the course objectives [16]. The assessment strategies are chosen in such a way that the levels at which the student achieves the objectives are assessable and measurable.

The backward design has the advantage of using genuine engineering problems as a starting point for the development of the curriculum. The student's ability to solve real engineering related problems is a key graduate attribute mandated by the IEA [2], which may be demonstrated by students who integrate theory with practice. This integration has been under discussion for many years when it comes to engineering courses [17]. Engineering students must be assisted in the practical application of theory where real life engineering problems are addressed [18]. The context of the problem must be presented to students who must use their newly acquired theoretical knowledge to solve the problem, which really gives rise to problem-based learning [19]. Problem-based learning usually starts with the learning outcomes [20] which assist students to gain more insight into the theory through application, rather than just insight into theory itself.

Learning outcomes need to be specific, measurable [21] and manageable, being introduced to students at the beginning of the semester [22]. Literature suggests a correlation between a small number of learning outcomes and unsuccessful students [23], while on the other hand it can intimidate some students if too many learning outcomes exist in a single module [24]. The number of well-defined learning outcomes must correlate to the number of hours a student must spend in the module. It is also essential that learning outcomes be well-defined, so that the rest of the course material and assessments can be compiled to support it [25]. Constructive alignment must be adhered to if the setting of an environment, where all the learning activities are to be completed, is to lead and help students to achieve the learning outcomes and complete the assessments successfully. Learning outcomes must indicate to a student what he or she must be able to do or demonstrate at the end of the module [26], which, in the context of this study, is a Solar Energy Systems course.

III. CONTEXT OF THIS STUDY

The Department for Electrical, Electronic and Computer Engineering at CUT offers courses in electrical and computer engineering. These courses deal with the study and application of electricity, electronics, electrostatics and electromagnetism, which covers a range of sub-studies, including power electronics, control systems, signal processing and telecommunications.

The HCRET was designed for those individuals that want to enter the renewable energy field as technicians, thereby enabling students to prove that they have achieved a basic knowledge of the fundamental principles of the application, design, installation and operation of PV, Solar and Small Wind energy systems. A total of 120 credits is required for the HCRET and is currently a NQF level 5 certificate. This certificate requires a full year of instruction [27] where one of the required modules is termed Solar Energy Systems II. This module forms the basis for this research paper and is discussed in the following sections.

A. Design and Development of Practical Instruction for Solar Energy Systems II

The course structure of the module is divided into five main theory sections. Students are required to complete two written class tests that contribute 25% and 40% towards their total course mark. The other 35% of the course mark is derived from the practical instruction which is completed in a laboratory using an innovative jig and accompanying software that was developed by the authors [28]. Students are given a final summative written assessment (examination) at the end of the semester, which covers both the theoretical and practical instruction. The student's final mark is calculated using 40% of the course mark and 60% of the examination mark.

Although a close relationship exists between the theory and the practical instruction, this paper only focuses on the design and development of the practical instruction. The five learning outcomes of the practical instruction are presented next.

B. Learning Outcomes for Practical Instruction

Five learning outcomes were identified in close collaboration with all stakeholders in the PV field. The identified learning outcomes are as follows based on the relevant scientific literature:

- Document the effect that various tilt angles have on the output power of a PV module [29];
- Assess the influence of temperature on the output power of a PV module [30];
- Verify the negative impact of shading on the output power of a PV module [31];
- Clarify the influence of different light intensities on the output power of a PV module [32]; and
- Determine the I-V curve of a PV module [33].

C. Assessment Strategies

Possible assessment strategies include focus group interviews, senior exit surveys, laboratory reports and practical tests [34] while assignments, skill demonstrations, examinations, learning journals and projects may also be used [35]. After careful consideration, it was decided to firstly use skill demonstrations in terms of having students do an oral presentation of their experimental results. Secondly, written laboratory reports of the assignment with the documented results are required. Finally, a written class test was scheduled after all the learning outcomes were completed. The laboratory report consists of the following sections:

- Objective: students must state the objective of the experiment
- Hypothesis: students need to state the expected outcomes of the experiment
- Materials: students must provide a detailed list of all the equipment that was used to complete the experiment
- Procedure: students need to systematically list all the steps that must be followed to obtain the results and complete the experiment
- Observations: students must list all observations while completing the experiment
- Data: students need to provide a table containing all the results of the experiment
- Conclusion: students must draw conclusions that relate to the experimental question
- Reflections: students need to reflect on the meaning and relevance of the experiment

D. Pedagogical Methods

Possible pedagogical methods include, but are not limited to, assigned readings, lectures, case studies, examinations, individual and/or group work, creativity and innovation, handouts, videos, workshops, seminars, interviews with entrepreneurs, role playing, mentors, competitions, guest speakers, e-learning and online learning, simulation, blended learning and engagement [36]. Alternative pedagogical methods include authentic learning, case-based learning, inquiry-based learning, and problem-based learning [37]. The main pedagogical method which was selected involved an authentic learning task, where a physical PV module was exposed to various controlled parameters, while the student could observe the associated results on a computer screen. These controlled parameters simulate the physical environment which a PV module could be exposed to in practice. The PV module and the controlled parameters were incorporated into an innovative jig that could be used by students to demonstrate the achievement of all five learning outcomes of the practical instruction.

The use of this innovative jig (a form of authentic learning) in conjunction with an ARDUINO board and LabVIEW simulation software (a form of computer-based learning) has made it possible for students to enjoy a valuable learning experience that has proved to be an enabler for them to demonstrate the desired learning outcomes. The ability to work in any location, to be able to run simulations and to make use of the internet is just few advantages of Computer-based learning [38, 39]. Other pedagogical methods which were used include lectures, group work, videos and a learning management system.

E. The syllabus and content

The fourth step in the backward design process is to design the syllabus in such a way that it aligns with the learning outcomes as well as the assessment strategies. The fifth and final step involves identifying a prescribed textbook, e-book or e-files which students may consult while completing the practical instruction. Table I outlines the five steps which were followed in the design and development of the practical instruction.

IV. Student Perceptions of the Practical Instruction

The focus on student perspectives is important in this study because it permits for a better understanding of how the academics performance and course design may lead to deeper and more continued learning [40].

Fig. 1 presents the results of the student feedback regarding the practical instruction which they received in this module. The sample size was 33.

An overwhelming majority of the students indicated that they enjoyed the practical work (92% as indicated by adding the 59% (Strongly Agree) with the 34% (Agree)). The question regarding how challenging the practical instruction was provoked a mixed reaction, as 34% of the students felt that they were challenging while 29% felt that they were not challenging. 97% of the students indicated that the module was a valuable learning experience. In response to the question whether the practical work helped students to better understand the theory, 97% of the students indicated that it was indeed helpful. This tends to suggest that the practical work promoted student engagement with the course material [41], leading to a more rewarding educational experience. In response to the question regarding the application of new knowledge, 85% indicated that they learned how to apply new knowledge in solving engineering problems. In response to the question whether the practical instruction was relevant to the theory discussed in the classroom, 83% of the students agreed. These results tend to suggest that a measure of student satisfaction was achieved with regard to the practical work, thereby implying that they will be more motivated to complete their studies [42].

TABLE I. STRUCTURE OF DEVELOPED PRACTICAL CURRICULUM FOR SOLAR ENERGY SYSTEMS II

Learning outcomes that students must be able to	**Assessment**	**Pedagogical methods**	**Syllabus**	**Content**
Document the effect that various tilt angles exert on the output power of a PV module	End of module test on practical work Practical laboratory report Oral presentation by student	Innovative Jig (authentic learning) Arduino board and computer software (computer-based learning) Lectures Videos Learning management system	Solar system configurations	Journal articles Conference papers E-Books Web pages
Assess the influence of temperature on the output power of a PV module			Design of PV systems	
Verify the negative impact of shading on the output power of a PV module			Components of a Solar Electric System	
Determine the I-V curve of a PV module			DC and AC measurements on PV systems	
Clarify the influence of different light intensities on the output power of a PV module			Introduction to solar energy	

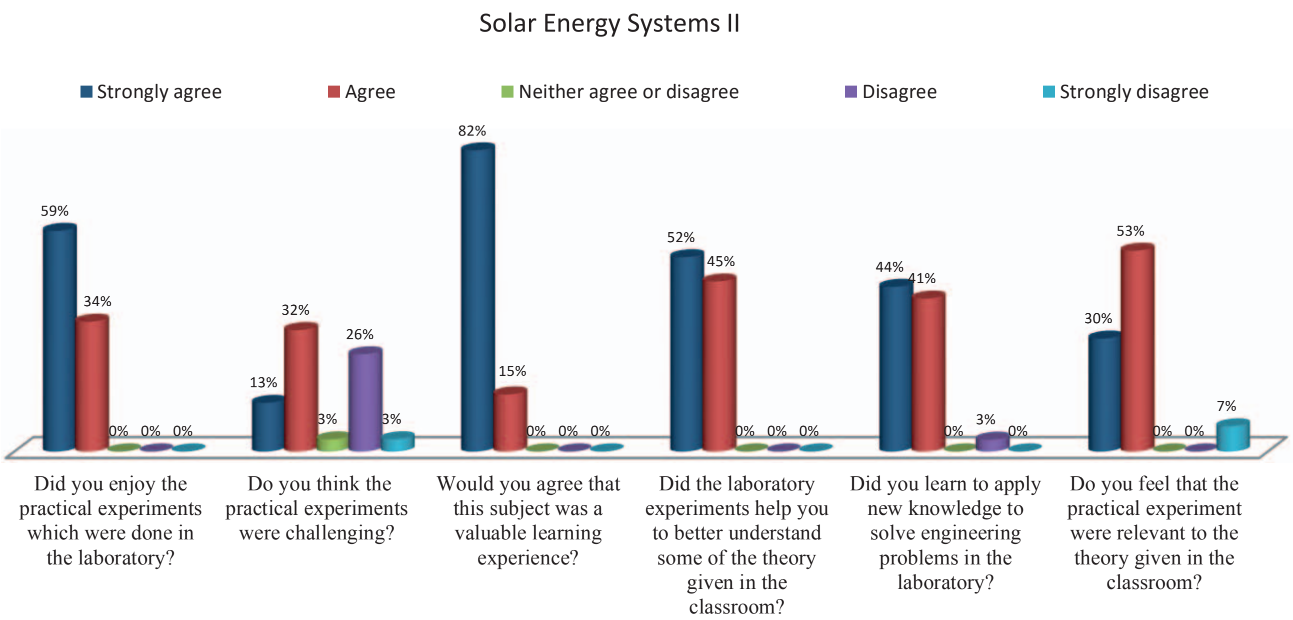

Fig. 1. Student perspectives of practical work that was done in a Solar Energy laboratory

V. CONCLUSIONS

The purpose of this paper was to describe the design and development of relevant practical instruction which was introduced into one of the solar energy modules, termed Solar Energy Systems II, which forms part of a new renewable energy course offered at CUT. The backward curriculum design method was applied in developing the practical instruction, were five distinct steps were discussed. Five learning outcomes were specified while three assessment strategies were selected, including oral presentations, written laboratory reports (headings include the experimental question, hypothesis, materials, procedure, observations, data, conclusion and reflections) and a final written class test. Two main pedagogical methods where used involving authentic learning and computer-based learning, while lectures, group work, videos and a learning management system were also used, but to a lesser degree. 94% of the students were able to successfully achieve the learning outcomes which were assessed by means of a final examination. Student perceptions of the practical instruction revealed that it was enjoyable (92%), relevant to the theory (83%), and a valuable learning experience (97%). This practical instruction has given freshmen engineering students the opportunity to demonstrate their acquisition of important graduate attributes that may help them to contribute to the socio-economic development of South Africa.

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