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Intellectual Development for Sustainability in Design and Manufacturing

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Abstract

Engineers have a crucial role to play in today's world. The future directions are based on the decisions and actions that we make today. The penalties of making the wrong decision may be serious for the future generations. Sustainability is an important issue for any organization in the twenty first century and has become an integral part of the engineering practices and policies. Engineers have a critical role to achieve this with sustainable development. Engineers should not ignore the challenges and opportunities that arise from the needing sustainability development, and sustainability is a key driver for new directions in engineering all the way from design to manufacturing. Systems thinking, problem-finding, visualizing, improving, creative problem-solving and adaptability are the six types of cognitive abilities that engineering students need to develop as identified by the Royal Academy of Engineering [1]. All the above mentioned requires an understanding of multiple views and the application of knowledge in relation to sustainability.

Most engineering students in the Middle East start their first year undergraduate studies believing that the right answer is either at the back of the book or what the teacher expects for an oral or written in a test. This kind of thinking is dualistic and was already identified as the starting point for most undergraduates in the 1970s by Perry's [2] in model of intellectual development. It also parallels with the revised Bloom's taxonomy [3]. In order to investigate whether the students' sustainability thinking skills change over time a survey based on epistemic beliefs inventory is created and deployed to Freshman students on an introductory course to engineering and to Sophomore students studying the basics of engineering design. The authors in this paper would discuss the results of the survey and recommended actions based on the survey.

Introduction

Higher educational institutions have recognized and acknowledged their responsibility towards achieving the goals of sustainability as they prepare the future engineers for the global world. Sustainability challenges all schools and universities to rethink their mission and vision to represent themselves as the new generation school. With this in place most of the accrediting bodies have also included the ethical part of sustainability in the curriculum, which makes most of the program to restructure and realign the curriculum, develop research programs, and redefine the student life activities. Most of the graduate students are exposed to the political, ethical, scientific, and design challenges while in school they deal with conflicting norms and values mixed with uncertainty of outcomes and futures, and a changing knowledge base. At the same time, they will need to be able to contextualize knowledge in an increasingly globalized society. There are several studies have been done on the kinds of qualifications, knowledge and skills that the 21st century engineer should have. To illustrate an example of such skills reflecting the needs of industry, Rajala [4] defines the areas of competence necessary for a global engineering professional as global competence, technical competence and professional competence. However, she points out that the attributes associated with each of these competences present a challenge for engineering educators in both the context in which they should be introduced, as well as "determining what can be accomplished within the constraints of a university education" [4]. From an educational stance, the Accreditation Board for

Engineering and Technology (ABET) [5], states engineering students' minimum learning outcomes (a) through (k) as shown in Table 1:

Table 1: ABET learning outcomes

a) an ability to apply knowledge of mathematics, science and engineering
b) an ability to design and conduct experiments, as well as to analyze and interpret data
c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
d) an ability to function on multidisciplinary teams
e) an ability to identify, formulate, and solve engineering problems
f) an understanding of professional and ethical responsibility
g) an ability to communicate effectively
h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
i) a recognition of the need for, and an ability to engage in life-long learning
j) a knowledge of contemporary issues
k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The lists of competences, attributes and learning outcomes are based on much research and have been modified over time to ensure that engineering education develops along with industrial needs and college learning outcomes are adjusted accordingly. Feedback is also frequently sought from industries [4], which have become more and more multinational, another aspect that affects the nature of learning outcomes in engineering education.

However, the extent to which undergraduate engineering students choose to acquire the desired qualities or skills depends greatly on the types of epistemic beliefs that they have. Epistemology is the philosophic study of where one believes knowledge comes from and what it is like [6]. Epistemic beliefs can be related to research, personal knowledge or professional knowledge among other things. The Epistemic beliefs survey is modified to fit into the sustainability aspect and to see if there is any significant difference between the freshmen students and sophomore students at the Petroleum Institute. As far as college education is concerned, the person who is recognized as the pioneer in developing the first framework of the kinds of knowledge that undergraduate students have is William Perry [1]. According to Perry [7], undergraduate students can go through four hierarchical levels of knowledge development as follows; the first stage is dualism (knowledge is either right or wrong as determined by a figure of authority); stage two is multiplicity (knowledge is about differing opinions); stage three is called relativism (knowledge is dependent on context) and stage four, which Perry called 'commitment' whereby knowledge is the ability to make decision based on informed opinions. In studies done on undergraduate engineering students using Perry's model in the USA in the 1980s, 1990s and at the start of the 21st century, "most engineering undergraduates complete college in the lower classifications of either dualism or multiplicity” [1]. According to [8], Perry’s model is the most common model used to measure an understanding of where knowledge comes from in engineering education.

There is a growing body of evidence showing that personal understanding and knowledge is a critical component of student learning [10]. Schraw, Dunkle, and Bendixen [11] designed beliefs survey to measure five constructs concerning the nature of knowledge and the origins of individuals’ abilities which was based on the earlier work of Schommer [12], he primary purpose of this study was to the knowledge and belief of the students related to sustainability.

Education had always been an integral part of the United National sustainable development agenda. The World Summit on Sustainable Development (WSSD) in 2002 adopted the Johannesburg Plan of Implementation reaffirmed the achievement of need to integrate sustainable development into formal education at all levels, as well as through informal and non-formal education opportunities. Both the Muscat Agreement adopted at the Global Education For All Meeting (GEM) in 2014 and the proposal for Sustainable Development Goals (SDGs) developed by the Open Working Group of the UN General Assembly on SDGs (OWG) include ESD in the proposed targets for the post- 2015 agenda. The proposed Sustainable Development Goal 4 reads "Ensure inclusive and equitable quality education and promote life-long learning opportunities for all" and includes a set of associated targets [7].

Background

The Petroleum Institute (PI) was created in 2001 with the goal of establishing itself as an international institution in tertiary engineering education and research in areas of significance to the oil and gas and the broader energy industries. Currently the PI offers Bachelor degrees in Chemical, Electrical, Mechanical, Petroleum Engineering, and Petroleum Geosciences. The students after they go through the high school are admitted based on their TOEFL score and the GPA in high school. Most of the students go through a foundation program before they are enrolled as a freshmen student in PI. The foundation program is designed to help students develop knowledge, study skills, technical, analytical, and communication skills which are necessary to meet the PI’s entrance requirements and assist them in their future studies at the Petroleum Institute. The foundation program at the PI is called as the Academic Bridge program.

Once the student reaches the freshmen level there are core courses that have to complete irrespective of their majors. The core courses are offered through the Arts and Science Program and some elective courses required for the engineering programs are also offered through Arts and Science. The six departments within the Arts and Science department include Mathematics, Physics, Chemistry, Humanities and Social Sciences, Communication, and General Studies. Students must take these required courses in a sequence.

The general studies department offers a sequence of three courses. In the freshmen year students take, the introduction to petroleum engineering in the petroleum industry followed by two sophomore design courses called STEPS, which stands for Strategies for Team-based Engineering Problem Solving. In STEPS courses students integrate what they are learning in science, mathematics and communications, couple it with teamwork and project management tools and build a working prototype of a useful machine. The requirement to start the STEPS courses is that they should complete the first course of Physics and two levels of communication class. After successful completion of the courses in Arts & Sciences, students enter one of the six engineering departments to do upper level courses and pursue a specialized engineering degree program.

The Institute strives to develop students as whole persons and as the future leaders in their respective fields of expertise in the UAE and globally. ADNOC the sponsor company of The Petroleum Institute has taken serious steps to fulfill their commitment towards sustainability. Students at the institute opt to study engineering majors for a variety of reasons, including parental pressure. A job in any field of engineering, but specifically in the field of Petroleum Engineering is seen as demanding and highly respected, guaranteeing a very acceptable status in society. As future employees at ADNOC, students should be fully aware of the implications of the consequences of the quality of their work [9], which is guided by their knowledge in sustainability. These in turn affect the students' work ethics and the way they view the discipline of engineering. The aim of the current study is to understand what kinds of beliefs does the students develop in sustainability from the freshmen year to the sophomore year.

Methodology

The data for the current study were gathered from STPS 201 (sophomore course) course as well as with the ENGR 101 (freshmen course) students. The case study consisted of a total of 21 female students enrolled in the ENGR 101 freshmen year engineering course and 20 students with the sophomore course on engineering design called STEPS 201. Both courses were taught by the same instructors. The sustainability beliefs survey was developed based on the concepts of the of the Epistemological beliefs inventory [3]. This quantitative measuring instrument is designed so that individuals respond using a 5-point Likert-type rating scale from strongly disagree (1) to strongly agree (5) to items concerning their beliefs about education and learning. The inventory was developed to measure five underlying constructs: Certain Knowledge, Innate Ability, Quick Learning, Simple Knowledge, and Omniscient Authority. The inventory, abbreviated as EBI, consisted of 32 Likert-type questions designed to measure five subscales of different types of knowledge. The subscales for the five categories included simple knowledge, which was set to define how complex knowledge is, certain knowledge regarding how tentative knowledge is, omniscient knowledge (how knowledge is acquired through authority), quick learning (how quickly knowledge is obtained), and innate ability (one's innate ability to gain knowledge) [3]. Table 2 shows the categories of questions.

TABLE 2: Categories of questions

Simple Knowledge	1. It bothers me when instructors don't tell students the answers to complicated sustainable problems. 9. If a person tries too hard to understand sustainability, they will most likely end up being confused. 10. Too many theories just complicate things. 11. The best ideas are often the simplest. 13. Instructors should focus on facts instead of theories on sustainability.

	18. Sustainability is simpler than most professors would have you believe. 22. Sustainability is easy to understand because it contains so many facts. 24. The more you know about sustainability, the more there is to know.
Certain Knowledge	2. Sustainability means different things to different people. 6. Absolute moral truth does not exist. 7. Parents should teach their children all there is to know about sustainability. 19. If two people are arguing about sustainability, at least one of them must be wrong. 25. What is true about sustainability today will be true tomorrow. 31. Sometimes there are no right answers to debated sustainable problems.
Omniscient authority	4. People should always obey guidelines for sustainability. 14. I like teachers who present sustainability ideas and let their students decide which is best. 20. Children should be allowed to question their parents' belief in sustainability 23. The moral beliefs in sustainability that I live by apply to everyone. 27. When someone in authority tells me what to do, I usually do it. 28. People who question sustainability are careless.
How quickly knowledge is obtained	3. Students who learn sustainability are the most ones who appreciates sustainability 16. If you don't learn sustainability quickly, you won't ever learn it. 21. If you haven't understood an aspect about sustainability the first time through, going back over it won't help. 29. Working on a sustainability problem with no quick solution is a waste of time. 30. You can study sustainability for years and still not really understand it.
Innate ability to gain knowledge	5. Some people will never believe in sustainability no matter how much they know 8. Really smart students don't need a lot of guideline to follow sustainability 12. People can't do too much about how sustainable they are. 15. How well you perform in society depends on how much you comply to sustainability. 17. Some people just have a knack for sustainability and others don't. 26. Sustainable believers are born that way. 32. Some people are born with care and passion to future generation

Results and Discussion

After administering the survey results for the female students, the data analysis was completed. The following two tables shows the results for the freshmen students who took ENGR 101 (table 3) and for the sophomore students who took STPS 201 (table 4).

Table 3: Survey results for ENGR 101

Subscale	Range	Mean	SD
Simple Knowledge	3.25-4.08	3.78	0.26
Certain Knowledge	2.75-4.17	3.40	0.54
Omniscient authority	2.25-4.25	3.65	0.74
How quickly knowledge is obtained	2.33-3.75	2.85	0.58
Innate ability to gain knowledge	2.08-3.83	3.03	0.57

The sub scale simple knowledge focuses on whether knowledge consists of discrete facts, Certain Knowledge concerns whether absolute knowledge exists or does it change over time, Omniscient Authority indicates whether knowledge is transmitted by authorities or obtained through personal experience, Quick Learning examines whether learning occurs in a quick, and finally Innate Ability explores whether the ability to acquire knowledge is endowed at birth

Table 4: Survey results for STPS 201

Subscale	Range	Mean	SD
Simple Knowledge	2.57-4.5	3.58	0.58
Certain Knowledge	2.29-4.29	3.39	0.83
Omniscient authority	2.14-4.43	3.55	0.85
How quickly knowledge is obtained	2.0-3.71	2.77	0.64
Innate ability to gain knowledge	1.86-4.29	2.95	0.8

As you see from Table 3, students have strong opinions on their simple knowledge, certain knowledge, and omniscient authority. Table 4, is also no different in the values and a comparison spider web (Fig 1) shows that the pattern for both ENGR 101 and STPS 201 are very similar.

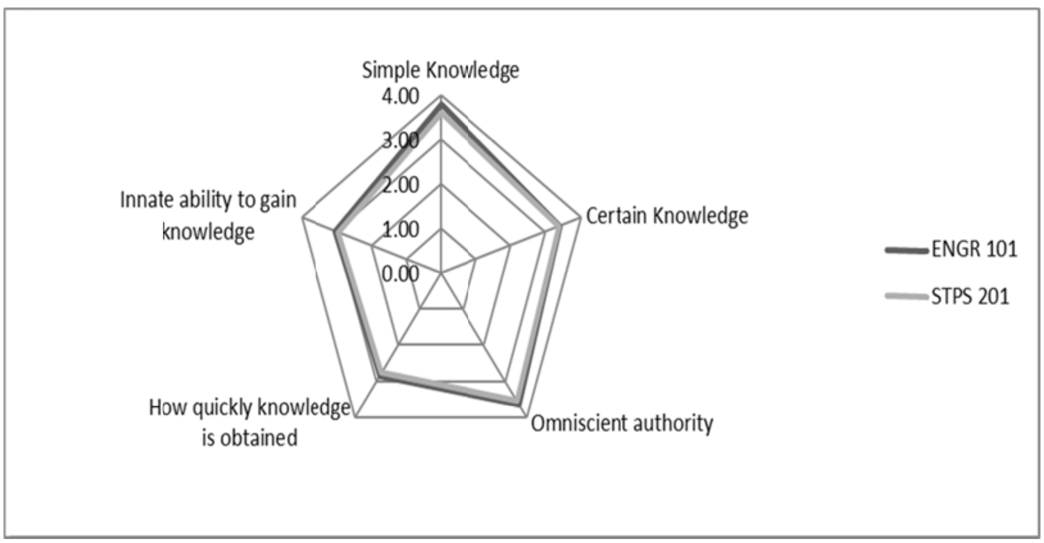

Fig (1) Comparison between ENGR 101 and STPS 201

Considering the amount, the students have studied it can only be deduced that students continue to rely on their instructors for the right answers whether it is at the freshmen level or sophomore level. So when a topic like sustainability is introduced it needs to be tackled from all the directions, inside the classroom, student activities, projects, and campus wide initiatives. Engineers use critical and creative thinking to solve all kinds of open-ended problems with habits of mind as systems thinking, problem-finding, visualizing, improving, creative problem-solving and adaptability. All these ways of thinking include an element of uncertainty in them. The results show the inability of the student to gain knowledge on their own. Students are not prepared to reach into the unknown as readily as perhaps college instructors would like to think. As a result, the matter becomes a curricular issue, because these kinds of thinking skills are required in industry and business to sustain. This is why students need to be exposed to more and more real life problem finding and solving situations, as well as experiential learning that would be related to sustainability.

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