Proceedings of the IETEC'13 Conference, Ho Chi Minh City, Vietnam.

CDIO Curriculum for Multidisciplinary Engineering Undergraduate Course

Abdulkareem Sh. Mahdi Al-Obaidi
Taylor's University, Kuala Lumpur, Malaysia
abdulkareem.mahdi@taylors.edu.my

Koay Song Leng
Taylor's University, Kuala Lumpur, Malaysia
sonny_ksl@hotmail.com

Chan Yen Min
Taylor's University, Kuala Lumpur, Malaysia
hataru1991@hotmail.com

Tam Sue Wern
Taylor's University, Kuala Lumpur, Malaysia
rainie_tsw@live.com

Tan Xin Ying
Taylor's University, Kuala Lumpur, Malaysia
r_ying715@hotmail.com

Goh Sze Ting
Taylor's University, Kuala Lumpur, Malaysia
gohszeting@hotmail.com

Chan Sze Ney
Taylor's University, Kuala Lumpur, Malaysia
szeney@gmail.com

ABSTRACT

To use Project Based Learning to transform an old curriculum to a new CDIO curriculum is a unique approach. The approach helps to carefully select projects for the Multidisciplinary Engineering Design modules to address a challenging issue in gaining access to drinkable water. The students in the first semester second year in a four-year engineering were formed into group. They were assigned the tasks of conceiving, designing, implementing and operating in their multidisciplinary projects. A group of mechanical and chemical engineering students conceived an idea to design a pedal-powered concept vehicle that transports, filters, and stores water. A tricycle is designed as a means of transportation. The tricycle consists of a *peristaltic pump that aids the water flow and a filtration system that purifies dirty water. The results show that the filter is able to reduce up to 70-80% of microbes. The proposed tricycle provides solutions to three problems when collecting water as: bigger amount for each trip, easy yet stable transportation, and filtration. After completing the projects, students also learnt how to apply the CDIO concepts and had an opportunity to work on a real-life project with significant social impact.*

Keywords: *CDIO, Multidisciplinary, Drinkable water, Tricycle*.

1. INTRODUCTION

There is an increasing need for grooming engineering students "*who can engineer*", be employable and able to overcome challenges, particularly the grand challenges. Hence, there is a need for engineering students to possess a wide array of personal, interpersonal, and system building knowledge as well as skills that allow them to perform in real engineering teams to produce real products and/or systems that meet both enterprise and societal needs (Crawley, 2001).

The educational institutes, organizations and accreditation bodies continuously address this issue, through which they define several aspects of successful engineering education. Among these aspects are "*an ability to function on multidisciplinary team*" and "*the broad education necessary to understand the impact of engineering solution in a global, economic, societal, and environmental context*" (ABET, 2011). For example, United Nations Educational, Scientific, and Cultural Organization (UNISCO) defines four generic pillars of education as "*Learn to know"*, "*Learn to do"*, "*Learn to live together"* and "*Learn to be*" (UNESCO, 2011). The Accreditation Board of Engineering and Technology (ABET) defines a number of criteria that assure quality and foster a systematic pursuit of improvement in the quality of engineering education. Doing so will satisfy the needs of constituencies in a dynamic and competitive environment.

In addition to that, the global challenges such as climate change, security and economic growth set the scene to an emerging global competence that is expected from engineers (Parkinson, 2009). In 2009, the National Academy of Engineering (NAE) identified 14 Grand Challenges that need to be addressed by engineers for the sake of humanity to make it sustainable in the next century. Among these challenges, one of them is to "*Provide access to clean water*" (NAE, 2008).

Water is essential components of all life. Insufficient water leads to dehydration, nausea, heart palpitation, and even death in serious cases. Despite the fact that 70% of the earth is covered with water, only 2.5% of the water on earth is fresh water. Out of the 2.5% of fresh water, two-thirds are frozen in glaciers and polar ice caps. Therefore, all human and other life depend on less than 1% of the total amount of water on this planet (Silk & Siruna, 2005). Based on the research done by WHO and UNICEF, more than one billion people don't have access to clean water, 1.4 million children die every year from diarrhoea caused by unclean water and poor sanitation (Sprenkle, 2010). Figure 1 shows that Eastern Asia and Sub-

Saharan Africa suffered the most severe water crisis. In Sub-Saharan Africa, treating diarrhoea consumes 12% of the health budget. On a typical day, more than half the hospital beds are occupied by patients suffering from faecal-related disease (UNICEF, 2011).

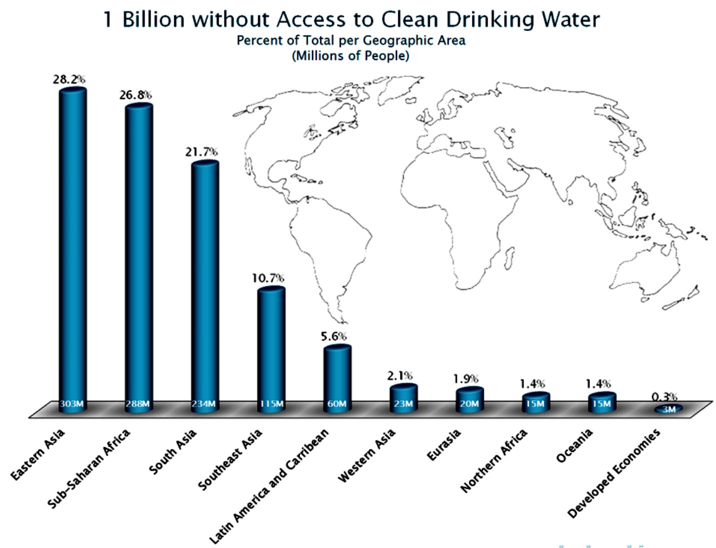

Figure 1: Percentage of People without Access to Clean Drinking Water (Sprenkle, 2010).

Grounded on the premise above, it is critical to produce innovative solutions to "Provide access to clean water". The Conceive-Design-Implement-Operate (CDIO) initiative is one of the widely accepted solutions to address all these engineering issues. CDIO initiative advocates an engineering education that stresses the fundamentals and is set in the context of the product-system lifecycle, which can be thought of in four metaphases: Conceiving-Designing-Operating-Implementing (Bankel et al., 2005). The CDIO-initiated engineering education normally uses educational approaches that are active, hands-on and project-based in order to achieve integrated learning, where the acquiring of disciplinary knowledge and CDIO skills takes place simultaneously. The philosophy of the CDIO initiative is outlined by the 12 standards and the syllabus it adopts. The CDIO syllabus (Crawley, Lucas, Malmqvist, and Brodeur, 2011) and standards (CDIO, 2004) are listed in Figure 2 and Table 1 respectively.

The aim of this paper is to use "Multidisciplinary Engineering Design" module to address one of the grand challenges; access to drinkable water by adopting the CDIO syllabus and applying the concepts of CDIO.

Table 1: CDIO Syllabus Version 2.0 at the Second Level of Detail (Crawley et al., 2011).

1 Disciplinary knowledge and reasoning	**3 Interpersonal skills: teamwork and communication**
1.1 Knowledge of underlying mathematics and science	3.1 Teamwork
1.2 Core fundamental knowledge of engineering	3.2 Communications
1.3 Advanced engineering fundamental knowledge, methods and tools	3.3 Communications In Foreign Languages
2 Personal and professional skills and attributes	**4 Conceiving, designing, implementing, and operating systems in the enterprise, societal and environmental context**
2.1 Analytical reasoning and problem solving	4.1 External, societal and environmental context
2.2 Experimentation, investigation and knowledge discovery	4.2 Enterprise and business context
2.3 System thinking	4.3 Conceiving, systems engineering and management
2.4 Attitudes, though and learning	4.4 Designing
2.5 Ethics, equity and other responsibilities	4.5 Implementing
	4.6 Operating

The CDIO™ Standards
Standard 1 -- CDIO as Context* Adoption of the principle that product and system lifecycle development and deployment -- Conceiving, Designing, Implementing and Operating -- are the context for engineering education
Standard 2 -- CDIO Syllabus Outcomes* Specific, detailed learning outcomes for personal, interpersonal, and product and system building skills, consistent with program goals and validated by program stakeholders
Standard 3 -- Integrated Curriculum* A curriculum designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal, and product and system building skills
Standard 4 -- Introduction to Engineering An introductory course that provides the framework for engineering practice in product and system building, and introduces essential personal and interpersonal skills
Standard 5 -- Design-Build Experiences* A curriculum that includes two or more design-build experiences, including one at a basic level and one at an advanced level
Standard 6 -- CDIO Workspaces Workspaces and laboratories that support and encourage hands-on learning of product and system building, disciplinary knowledge, and social learning
Standard 7 -- Integrated Learning Experiences* Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal, interpersonal, and product and system building skills
Standard 8 -- Active Learning Teaching and learning based on active experiential learning methods
Standard 9 -- Enhancement of Faculty CDIO Skills* Actions that enhance faculty competence in personal, interpersonal, and product and system building skills
Standard 10 -- Enhancement of Faculty Teaching Skills Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning
Standard 11 -- CDIO Skills Assessment* Assessment of student learning in personal, interpersonal, and product and system building skills, as well as in disciplinary knowledge
Standard 12 -- CDIO Program Evaluation A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement

An asterisk [*] indicates the essential standards

Figure 2: The CDIO Standards (CDIO, 2004).

2. LITERATURE REVIEW

Although project-based learning normally takes place in groups comprising of students of similar disciplines and backgrounds, there has been attempts to deliver project-based content to multidisciplinary groups. Herzberg and Sweetman (2005 2006) reported a new experimental course on flow visualisation that was offered to a mixed class of fine arts photography and engineering postgraduate students. The results from their experimental course illustrated that flow visualisation can be performed successfully by a wide range of people.

Shamel and Al-Atabi (2013) exposed students from a mechanical and chemical engineering background to an environment in which they are encouraged to interact with and engaged team members in a module "Product Design Exercise". The students, working in groups, were offered different open-ended projects that were selected to exploit the knowledge they developed. The students demonstrated a high level of cooperation and motivation throughout the period of the project. Effective communication and closing of knowledge gaps were prevalent. At the end of the project period, students produced a journal paper in lieu of the project report. Al-Atabi and Al-Obaidi (2011) used the "Engineering Design and Professional Skills" module, offered at the second semester of the second year within a four-year Mechanical Engineering course, in conjunction with a theory based module namely "Flows with Friction, Drag & Lift" offered at the same semester. The purposeful combined offerings created a CDIO environment without introducing any major changes to the syllabus of the theory based modules or to their assessment scheme. The students were divided into groups and each group was assigned the task of conceiving, designing, implementing and operating a fluid related project. The students exhibited a high level of engagement and motivation while gaining a better understanding of the real fluids related theory.

A team of students, in their first semester second year, applied the CDIO processes throughout the entire project in order to achieve the learning outcomes of a module in Multidisciplinary Engineering Design. By matching the Multidisciplinary module with the CDIO syllabus as well as applying all the four metaphases of CDIO, the students managed their multidisciplinary project. They came out with a simple but effective solution to address the challenge of the access to the drinkable safe water. The details and elaborations of these 4 processes will be further discussed in the Design Process of this project.

3. CDIO AND MULTIDISCIPLINARY ENGINEERING DESIGN

The application of the CDIO initiative requires an understanding and a mapping of the learning outcomes and the delivery method of the Multidisciplinary Engineering Design with the CDIO syllabus.

3.1. CDIO Syllabus

The CDIO Syllabus classified the learning outcomes into four high-level categories: technical knowledge, personal professional skills and attributes, interpersonal skills, and the skills specific to the engineering profession as described previously in Table 1.

3.2. Multidisciplinary Engineering Design Module Delivery

In "Multidisciplinary Engineering Design" groups of engineering students from 3 different disciplines, namely chemical, electrical, and mechanical, work together on selected projects. The module lasted for 14 weeks. There are a total of six learning outcomes in Multidisciplinary Engineering Design module as in Table 2. The task selected for this group is to make the students provide a solution to one of the grand challenges "provide access to clean water" as engineers. Extensive research leading to the manufacture of prototypes was the main activities that were executed by the students throughout the 14 weeks semester. The final product was showcased to critique during the "Engineering Fair" in the university which was held every semester.

Table 2: Learning outcomes for " Multidisciplinary Engineering Design"

No.	Learning Outcome
1	Explain the principles of design for sustainable development.
2	Apply the principles of physics to achieve a specific engineering task or to build an engineering artifact.
3	Evaluate different approaches to achieve a required end result.
4	Appraise and defend ideas.
5	Predict outcomes of suggested approaches.
6	Explain the benefits and barriers associated with multidisciplinary teams.

3.3. Mapping the learning outcomes

To enable the application of the concepts of CDIO in "Multidisciplinary Engineering Design" module, a correlation between the CDIO standards, in particular CDIO syllabus and the module learning outcomes of the module is required. Table 3 shows the mapping of the mapping of the common learning outcomes of this modules and CDIO syllabus. This is particularly essential to show whether the students are able to develop the competency within the module in terms of CDIO skills (Al-Atabi & Wan, 2011).

Table 3: Mapping of CDIO Standards/CDIO syllabus to the learning outcomes of the "Multidisciplinary Engineering Design" module.

Module's Learning Outcomes		CDIO Syllabus
LO1	Explain the principles of design for sustainable development	1.1 Knowledge of underlying mathematics and science 4.1 External, societal ad environmental context.
LO2	Apply the principles of physics to achieve a specific engineering task or to build an engineering artefact.	1.2 Core fundamental knowledge of engineering 4.4 Designing 4.5 Implementing 4.6 Operating
LO3	Evaluate different approaches to achieve a required end result.	2.1 Analytical reasoning and problem solving 2.3. System thinking
LO4	Appraise and defend ideas	2.2 Experimentation, Investigation, and knowledge discovery 3.3 Communicate in foreign language
LO5	Predict outcomes of suggested approaches	2.2 Experimentation, Investigation, and knowledge discovery 1.3 Advanced engineering fundamental knowledge, methods and tools
LO6	Explain the benefits & barriers associated with multidisciplinary teams.	2.4 Attitudes, though and learning 2.5 Ethics, equity and other responsibilities 3.1 Teamwork 3.2 Communication

4. DESIGN PROCESS

In this section the design process is explained in details. This process consists of early phase of design where the challenges faced the group are brainstorming. This phase is followed by the four CDIO metaphases and how the students apply them in their projects. In each phase, examples from the project activities are given to show the application of the CDIO standards.

4.1. Challenges Faced and Brainstorming Sessions

In developing and poor countries without clean running water, fetching and collecting water is often a daily routine for women and children. They need to walk an average of 6.4 km each day in order to retrieve water. Besides that, limited volume of water can be transported in each trip. There is also no assurance that the water collected is safe for drinking or cooking. The most preferable method to sterilize water is through boiling which means using natural resources and fossil fuels. This leads to deforestation and carbon dioxide production.

Considering these issues, the main challenge was defined. Eventually, the project students designed a human-operated vehicle with the combination of transportation and sanitation of water to provide clean and drinkable water to improve in order to improve the quality of life. The product was a pedal powered concept vehicle that allowed people to transport and filter water simultaneously which also saved a lot of time where they could spend the time for work, education and family. As a result, the pedal powered concept vehicle definitely improved the lifestyle and economy in rural areas or developing countries.

There were few types of pedal powered concept vehicle water filtration which were currently available in the market. They were costly and had complex mechanisms, expensive filters, and were stationary, which meant it was more time consuming to filter and to transport the water back from the sources. The bicycles were also heavy and bulky, causing it hard to balance and less stable. In order to increase the efficiency and to save cost, a tricycle fitted with a peristaltic pump and filter was designed and used.

4.2. Conceive

The Conceive stage includes customer needs definition, technology considerations, enterprise strategy, regulations, conceptual development, technical development, and business plans (Crawley et al., 2011). How the students applied this CDIO metaphase in their multidisciplinary project?

Applying all the above in the multidisciplinary project, the group of students carried out the initial study and preparation. The challenge in the group project was to design a combination of both transportation and sanitation of water (customer needs). Considering the technology, the final product of the project would be a pedal-powered concept vehicle that enabled a person to transport and clean water simultaneously in larger quantities and potentially lessening physical strain of the task. The pedal powered water filtration eliminated both the need for walking to the water sources and for using fire to boil the water. Besides that, the design was a result of conceptual development making the product very user-friendly due to it was easily to operate and balance it without any required specific skill. So it is suitable for everyone regardless of the age and gender (enterprise strategy and regulations). Hence, people can spend the time for work, education and family, and also can save fuel and natural resources such as wood (business plans.)

4.3. Design

The Design stage focuses on creating the design, that is, the plans, drawings, and algorithms that describe what will be implemented (Crawley et al., 2011).

For this stage, the tricycle was chosen instead of bicycle as at three-wheeled structure had better stability (plan). Students created a design of a peristaltic pump which was connected to the side gear of the pedal so that it would rotate when a user started to cycle. The device consisted of rubber tubing attached to rotor with a number of rollers. The tubing was continuously squeezed by the rollers which forced the liquid flow in the direction of revolving rotor (algorithm). Rubber tubing was used to channel water from the dirty water tank to the filter with the aid of peristaltic pump. Based on some calculations, the students came out with the design of an innovative peristaltic pump and used the Powershape software (drawing) to visualize the overall structure as shown in Figure 3.

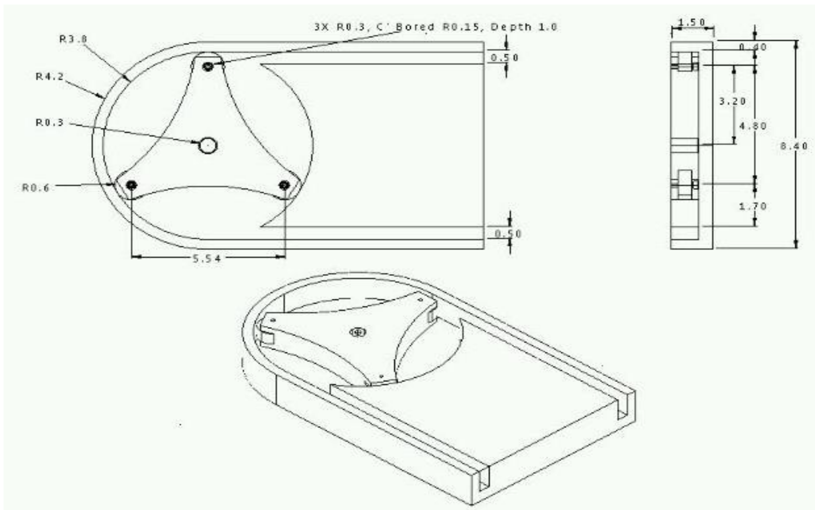

Figure 3: CAD Drawing of the Peristaltic Pump.

For the water filtration system, a point-of-use water filter (POU) was used in this project, which referred to a variety of different water treatment methods (physical, chemical and biological) used to improve quality of water for an intended use for drinking, bathing, washing, irrigation, etc., at the point of consumption instead of at a centralized scale. POU was chosen because the materials used inside the filter could be designed accordingly to the user need and POU used the principle of natural cleansing of the soil.

4.4. Implement

The Implement stage refers to the transformation of the design into the product, including manufacturing, coding, testing and validation (Crawley et al., 2011).

In order to implement the design and to convert a bicycle into tricycle, a shaft was an essential part to connect the main frame with the rear wheels. The shaft was implemented based on the children's tricycle mechanism, which was the simplest one (transformation). The shaft was designed in a way that could be removed when there was a necessity, and could be stored easily. Figures 4 and 5 show the back-wheeled shaft which consist of metal plates, ball bearings, free-wheel and metal rod, and also the application of it to the main frame (product).

Figure 4: The shaft design of the tricycle.

Figure 5: Application of shaft on the rear wheels to the main frame.

The implementation of the peristaltic pump, previously shown in drawing (Fig. 3) now is shown as a real product in Fig. 6 (manufacturing).

Figure 6: Peristaltic pump made up of metal plate and rollers.

As for the filtration system (product), it consists of several layers. The layers contain cloth filter, follow by polyester fibre filter, then super pro-volcanic pearl, bio-ceramic ball filter and lastly granular activated carbon or known as Charcoal filter (transformation and manufacturing). Based on experiments conducted in this project, the designed filter is able to remove up to 95-99% of the contaminants and pathogens in the water, thus it is safe for drinking and cooking. Figure 7 shows the filter that is made by the team.

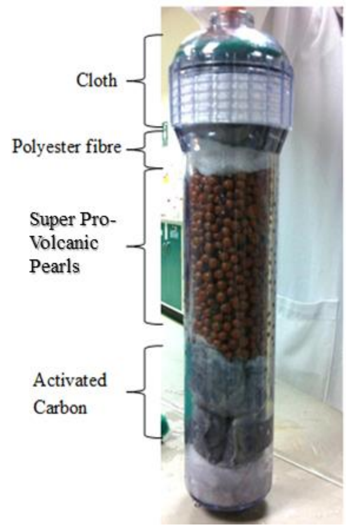

Figure 7: Design of water filter.

4.5. Operate

The Operate stage uses the implemented product to deliver the intended value, including maintaining, evolving and retiring the system (Crawley et al., 2011).

Pedal powered water filtration vehicle is a prototype aimed squarely at demonstrating principle of sustainability of engineering to solve the issues of clean water in developing countries. The final product which was a tricycle featuring a large rear platform for attachment of water tank. With removable water tank, it was easy to sanitize and convenient for users for specific purposes such as transport food, goods and etc. Peristaltic pump was chosen as it required no contact of the liquid with mechanical parts, hence no contamination happened as only interior part of tubing was in contact with fluid. Besides that, the tube was the only part to wear, so the maintenance costs were minimal (maintaining). At the estimated flow rate of 1.8 litres per minute, users were able to produce 108 litres of filtered water in an hour by using the pedal powered water filtration (evolving an retiring).

Having operated this product, it showed that the pedal powered water filtration provided a practical and efficient vehicle which is able to transport, filter and store water simultaneously. It was able to produce approximately 90 litres of filtered water per hour which was equal to the consumption of one or more families per day. Besides, the filter was able to reduce up to 97.12% of the contaminants in the water, providing a safe drinking water for the people.

5. RESULTS AND DISCUSSIONS

By applying the CDIO concepts into the multidisciplinary project to design a pedal-powered water filter, several learning outcomes were achieved during the process.

First, the group members were able to explain the principles of design for sustainable development. In this context, the project satisfied the environmental sustainability, economic sustainability and socio-political sustainability. Another achieved learning outcome was the application of the principles in physics. This was demonstrated through a simple designed mechanism which included the principles of physics.

Using different approaches to achieve a required result was also evaluated successfully during the multidisciplinary project. In addition, the group members also learnt the process of appraising and defending ideas, where they considered the pros and cons of specific products. The implemented products showed the essences of supporting scientific evidences through group effort in the group project.

Furthermore, another learning outcome of the project was to predict the outcomes of suggested ideas. By predicting outcomes, engineers are able to evaluate the probability of success of the project and thereby choosing the most suitable approaches in order to cut cost. As a final point, the benefits and barriers associated with multidisciplinary teams were to develop in the group members the abilities to explain as well as resolving conflicts and misunderstanding a and establishing the good relationship to move the project ahead.

As supported in the discussion above, all the achieved learning outcomes of this module are well aligned with the CDIO design process. So the students learnt what are important and the beneficial to them. It is achieved by adopting the four CDIO metaphases which led them to successfully complete the project on time and according to plan.

CONCLUSION

In conclusion, by applying the concept of CDIO throughout this entire project, the team of the students was able to achieve all the objectives and learning outcomes of the modules. The project was a great success as students exhibited a high level of engagement, commitment and motivation throughout the semester. In addition, the final product as a pedal powered water filtration provides a practical and efficient vehicle which is able to transport, filter and store water simultaneously. It is able to produce a desired amount of clean water enough to satisfy the daily consumption of one or more families. Besides, the filter is able to reduce up to 97.12% of the contaminants in the water, providing a safe drinking water for people. Hence, it is believe that the rate of water related illnesses in developing world will decrease tremendously. In other words, the product is a wise long-term investment and is able to address the problems faced by people in poor or developing countries.

REFERENCES

ABET. (2011). *Criteria for accrediting engineering programs*. Engineering Accreditation Commission. Retrieved April 15, 2013 from http://www.abet.org/uploadedFiles/Accreditation/Accreditation_Process/Accreditation_Documents/Current/eac-criteria-2012-2013.pdf.

Al-Atabi, M., & Al-Obaidi, A. S. M. (2011). CDIO curriculum for mechanical engineering undergraduate course. *Journal of Engineering Science and Technology* (*JESTEC*), 6(2), 251–259.

Al-Atabi, M., & Wan, W. Y. (2011) *Effect of reflective assessment on internalisation of CDIO principles*. Paper presented at the 7th International CDIO Conference, Technical University of Denmark, Copenhagen. Retrieved March 30, 2013, from http://www.cdio2011.dtu.dk/upload/ administrationen% 20%20101 /aus/cdio/conference_media/papers/114_paper. Pdf.

Bankel, J., Berggren, K. F., Engstrom, M., Wiklund, I., Crawley, E. F., Soderholm, D., El Gaidi, K., & Ostlund, S. (2005). Benchmarking engineering curricula with the CDIO syllabus. *International Journal of Engineering Education*, 21(1), 121-133.

CDIO Standards (2004). Retrieved April 25, 2013, from http://www.cdio.org/implementing-cdio/standards/12-cdio-standards.

Crawley, E. F. (2001). *The CDIO syllabus: A statement of goals for undergraduate engineering education* (MIT CDIO Report # 1). Massachusetts Institute of Technology, Department of Aeronautics and Astronautics.

Crawley, E. F., Lucas, W.A., Malmqvist, J., & Brodeur, D. R. (2011). The CDIO syllabus v2.0: An updated statement of goals for engineering education. Retrieved 25 April, 2013 from http://www.cdio.org/files/project/file/cdio_syllabus_v2.pdf.

Hertzberg, J., & Sweetman, A. (2005). Images of fluid flow: Art and physics by students. *Journal of Visualization*, 8(2), 145-152.

Hertzberg, J., & Sweetman, A. (2006). *Beautiful physics from ordinary fluids*. Paper 213 presented at the 12th international symposium on flow visualization. Retrieved May 30, 2013, from http://www.aaee.com.au/ journal/2003/mills_treagust03.pdf.

NAE (2008). Grand Challenges for Engineering. National Academy of Engineering, USA. Retrieved March 13, 2013 from http://www.engineering challenges.com.

Parkinson, A. (2009). The rationale for developing global competence. *Online Journal for Global Engineering Education*, 4(2), Article 2, 1-15.

Shamel, M., & Al-Atabi, M. (2013). Multidisciplinary projects for second year chemical and mechanical engineering students. *Journal of Engineering Science and Technology* (*JESTEC*), Special Issue on Engineering Education, April 2013, 87-92.

Silk, N., & Ciruna, C. (2005). *A Practitioner's guide to freshwater biodiversity conservation*. USA, Island Press.

Sprenkle, S. (2010). World water facts. Retrieved Nov 28, 2012 from http://www.africastories.org/africa-water-crisis/world-water-facts/#story.

UNESCO (2011). *The four pillars of education*. Retrieved April 15, 2013 from http://www.unesco.org/delors/fourpil.htm.

UNICEF, (2011). Wash booklet for seniors. Retrieved March 30, 2013 from http://www.unicef.org/zimbabwe/WASH_facts_-_WASH_booklet_for_seniors _IWSD.pdf