AN EXPLORATORY STUDY OF HOW SCHOLARSHIP OF TEACHING AND LEARNING (SoTL) INSPIRES THE USE OF THE CDIO FRAMEWORK IN ENGINEERING EDUCATION

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Abstract

The traditional perspective of teaching has for a long time been centred on "how much" content has been learnt by the students, resulting in the lecture method as the main teaching method. However, this method of teaching is progressively being replaced by one that focuses on "how well" the content has been learnt. According to Huber & Hutchings (2005), students are subsequently engaged more actively and become masters of their own learning. The Scholarship of Teaching and Learning (SoTL) undoubtedly enhances the development of innovative ways of teaching through learning practices that reflect on evidence. Through the reflection on evidence, and communication of results, SoTL has inspired a progressively innovative teaching method in the core module Professional Orientation, a project-based, first-year module presented in the UP EBIT ENGAGE programme. By inquiry and reflection on the way Professional Orientation students learn when doing the project activities in one project, the LEGO tower crane project, progressive re-curriculation had been done from 2010 to 2014. With the 2014 LEGO project, positive results were noted – a higher mean statistic (result) and a lower standard deviation statistic for the total weights lifted. Student feedback on conducting the project activities and on teamwork, were also positive. Future LEGO projects may yield even better results if lecturers employ a more holistic assessment rubric to include aspects such as the optimization of the budget. In general, the application of the CDIO framework as used in the LEGO project has additionally been found to enhance the integration of a student's learning experiences in acquiring knowledge for his or her/her discipline as well as developing skills such as teamwork, goal setting, conflict resolution and effective communication.

Keywords: Scholarship, Teaching, Learning, CDIO, framework.

1. INTRODUCTION

The Faculty of Engineering, Built Environment & IT (EBIT) at the University of Pretoria (UP) offers a 5-year Engineering Augmented Degree Programme (ENGAGE) to students who do not automatically qualify for a generic four-year Engineering degree programme.

While a minimum APS score of 36 is required for enrollment in the a four-year Engineering degree programme, a minimum APS score of 25 is needed to be considered for enrollment for the same degree but in the Engage programme, albeit with additional developmental modules and a further one year of study.

One key challenge for first-year Engineering students is the lack of real-life experience upon which they can base the engineering theories in subjects such as Physics. This lack of practical experience is an obstacle for students' ability to learn abstract theory in Engineering. One of the skills-based, project-oriented modules in the ENGAGE programme, called Professional Orientation, aims to enhance the integration of academic and life skills, communication skills, information technology, information management skills and professional conduct within an engineering education context. Since 2011 the CDIO framework has been incorporated as an innovative educational framework to nurture the production of the next generation of engineers.

In one of the projects in the module Professional Orientation, called the LEGO project, first year engineering students from nine engineering disciplines (Chemical, Electrical, Electronic, Computer, Industrial, Mechanical, Metallurgical, Mining and Civil) work in teams of five inter-disciplinary members on an exciting and engaging hands-on project to build a tower crane and compete in lifting maximum weights.

Applying the CDIO framework, students conduct research on the fundamental principles of operation of mechanical components such as gears, levers, pulleys, torque and tower cranes during the Conceive stage. Constraints such as time, money and rules are considered. A concept design of a tower crane, which the team intends to build, is developed during the Design stage. During the Implement stage, students build the tower crane according to the approved design, test their models and compete in lifting maximum weights. Finally, the Operate stage involves the finalisation of the model and writing up of a complete report on the project. The project report also includes a discussion section where results and teamwork are discussed giving students an opportunity for self-reflection and recommendations.

This paper therefore, seeks to highlight how the CDIO framework, as used in a LEGO project, contributes to the integration of the students' learning experiences while acquiring knowledge for their discipline. Additionally, how personal and interpersonal skills such as teamwork, goal setting, conflict management and resolution, and effective communication are enhanced.

Following, relevant information on SoTL, the CDIO framework, the Engage Programme and the module Professional Orientation is presented.

1.1 Scholarship of Teaching and Learning (SoTL)

According to Boyer (1997) research is defined as "Knowledge production and scholarship that covers the full spectrum from pure to applied…" This definition includes the scholarship of discovery, linking with original knowledge, the scholarship of integration i.e. scholarship across disciplines and time, the scholarship of application and finally the scholarship of teaching, which focuses on the systematic discovery of teaching and learning practices".

SoTL can loosely be defined as the scholarly enquiry into student learning, which advances the practice of teaching by making research findings public.

Two of the earlier definitions of SoTL supported in this paper, are the definitions by Cambridge (2001) and Martin, Benjamin & Trigwell (1999). The definition of Cambridge (2001) includes a number of components namely: "problem posing about an issue of teaching and learning", "studying the problem through methods appropriate to the disciplinary epistemologies", "applications of results to practice", "communication of the results", and finally "self-reflection and peer review". Martin, et al (1999) in turn define SoTL as "engagement with the existing knowledge on teaching and learning, self-reflection on teaching and learning in one's discipline, and public sharing of ideas about teaching and learning within the discipline."

In the words of Huber and Morreale (2002), SoTL reconceptualises teaching as an ongoing and scholarly process -"as a form of inquiry into student learning" (Huber and Morreale, 2002) - with an emphasis on improving student learning through continuous inquiry and engagement. In this they concur with Shulman (1999) who stated that SoTL has to comply with the same ultimate criteria as for all research:

- it is made public
- it becomes an object of critical review and evaluation by members of one's community
- members of one's community begin to use, build upon, and develop those acts of mind and creation

1.2 CDIO framework

During the twentieth century the models of engineering education evolved from a hands-on practice-based model (taught largely by practicing engineers) to the engineering science model in the middle of the century, taught mainly by engineering researchers. Although the latter laid a strong foundation of fundamentals, it placed less emphasis on actual engineering practice and consequently was criticised as having become too abstracted from engineering practice.

In the teaching of prospective engineers the university should not only educate technically expert engineers, but also those who can build and operate new value added engineering systems in a modern, team-based environment. As an evolution of the engineering science model, a few universities therefore adopted a problem-based learning model, in which projects became the organising principle of the education.

Four leading engineering universities (Chalmers University of Technology, Linko Eping University, the Royal Institute of Technology in Sweden and the Massachusets Institute of Technology in the USA) have partnered to create a new engineering education model, named CDIO. The CDIO Initiative, as the partnership is called, envisions an education that stresses the fundamentals, set in the context of the product-system lifecycle, which can be thought of as having four metaphases: conceiving, designing, implementing and operating. The design of a CDIO education reflects two goals: "that university students must develop a deeper working knowledge of the technical fundamentals, while simultaneously developing the skills to lead in the creation and operation of new products and systems" (www.cdio.org).

In the current article we support the view that graduating engineers should appreciate the engineering process (conceiving, designing, implementing and operating), be able to contribute to the development of engineering products, and to do so while working in engineering organisations i.e. a modern team-based environment. In order to develop complex value-added engineering systems, students must have mastered the fundamentals of the appropriate technical knowledge and reasoning. To work in a modern team-based environment, students must have developed the interpersonal skills of teamwork and communication. Finally, to create and operate products and systems, a student must understand something of conceiving, designing, implementing, and operating systems in the enterprise and societal context.

1.3 ENGAGE programme

The UP Engineering Augmented Degree Programme (ENGAGE) was offered for the first time in 2010. It is a 5-year extended degree programme. The design of the programme is underpinned by the following principles:

1. *Students should be supported in making the transition from high school to university.*
2. *Student workload (time students spend working) should be high throughout.*
3. *The volume of work (amount of content covered) should be low initially and increase over time.*
4. *Support should be high initially and decrease over time.*
5. *Students should encounter familiar subjects early in the program, less familiar subjects later on.*

The programme consists of the same mainstream modules that all BEng students take plus developmental modules:

- The mainstream modules are taken together with students in the 4-year degree programme.
- There are two types of developmental modules, augmented modules and skills-based modules. All of the developmental modules are structured to include elements that require the students to engage in the practices characteristic of successful students. These include having to attend classes (students may fail a module if they do not meet the attendance requirement) and submitting weekly assignments that are marked timeously and handed back to provide students with frequent feedback on their performance

The structure of the curriculum provides scaffolding for student learning and self-regulation by starting Year 1 with basic science subjects that are familiar from high school and a high proportion of developmental modules. In Year 2 students continue with the less familiar engineering modules and fewer developmental modules.

Augmented modules are thus offered in all level 100 basic science and engineering modules in Years 1 and 2 of the programme with the goals of addressing necessary background knowledge and to develop the conceptual understanding and problem-solving skills needed to succeed in the accompanying mainstream modules. Augmented modules have their own curricula—they are not merely extra tutorials—and are taught by lecturers who have both sound content knowledge and good teaching skills. Students are taught in groups of about 50 for four periods per week. One of these periods is a formal lecture and the other three are interactive "discussion classes".

1.4 Professional Orientation

Professional Orientation is a skills- and project-based module facilitated over two semesters in Year 1. The goals of Professional Orientation are to help develop students' communication, information technology, information management, academic and life skills, as well as professional conduct within an engineering context.

The LEGO project is offered in the second semester of Professional Orientation and aims to combine all skills developed and fine-tuned during the course of the first semester i.e.

- IT and information management skills
- Life skills (effective communication, team work, conflict management, using learning style preferences of all team members to improve the functioning of the team, effective time management)

- Academic skills (academic reading and technical report writing)
- Professional conduct

2. LEGO PROJECT

First-year UP ENGAGE Engineering students, from nine different engineering disciplines, were required to design and build a tower crane using LEGO pieces as shown in Figure 1.

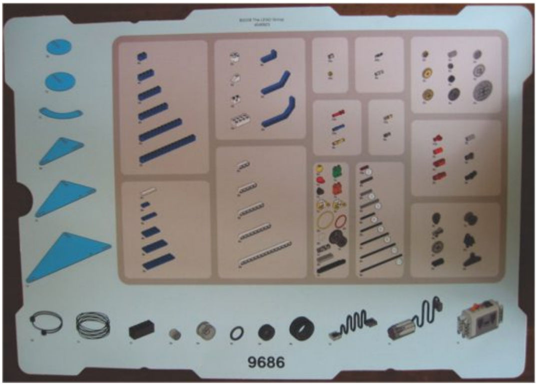

Figure 1: LEGO educational set 9686

The completed tower crane prototypes were subsequently used to attempt to lift as much weight as possible, for a distance of 15 centimetres, within a time period of 90 seconds. At the onset of the project, before the students started planning the design and executing the different processes, they were presented with the following scenario:

> *"You are a member of one of the design teams in an upcoming engineering firm. The firm has been contracted to design a crane system which should be able to lift a maximum weight within certain constraints. Various design teams in your company have been given this task which in the final phase will be assessed during a competition. The winning design will be developed further for implementation in industry"*

The students were not allowed to make up their own teams - team members for each LEGO team were pre-selected from the nine engineering disciplines. Hence, in Professional Orientation Group 1 students from industrial, civil, and chemical engineering were combined in teams and in Professional Orientation Group 2 students from mechanical, electronic, electric, computer, metallurgical and mining engineering were put together in teams. This was done for the purpose of students getting exposure to the different perspectives, and probably different aptitudes and interests, from the different team members.

In reality these combinations contributed to timetable clashes when students wanted to work on their cranes outside of class time.

2.1 The new LEGO project

In the first year of the ENGAGE programme in 2010 the students were required to individually work through a tutorial on the LEGO project on their own and thereafter embark on the project. In order to improve the teaching and learning in the module Professional Orientation in general, and the LEGO project in particular, it was however decided to incorporate some changes which resulted in a new LEGO Workshop workflow. The work flow shown in Figure 2, has been followed from 2011 up to 2014.

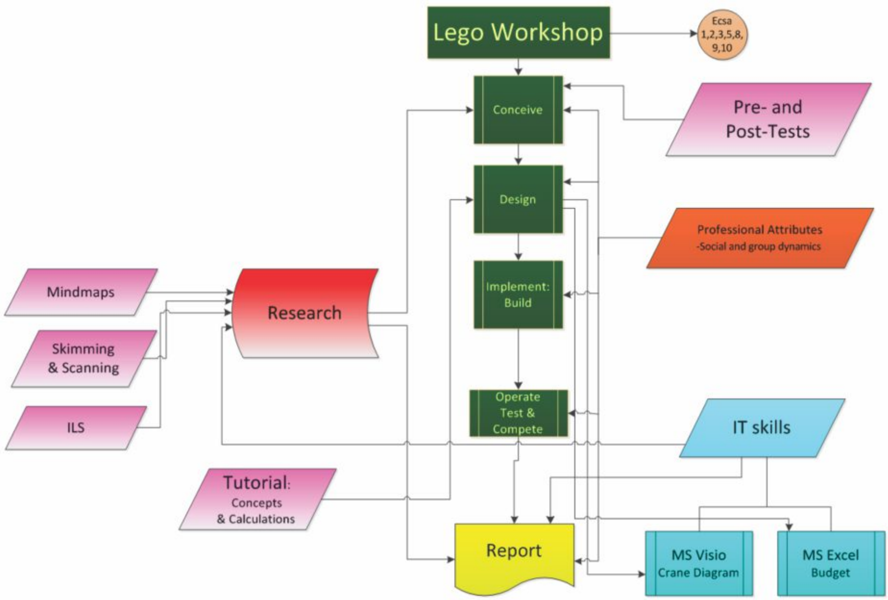

Figure 2: LEGO work flow

With the re-curriculation of the LEGO workshop for 2011 the following supportive steps, have systematically, been introduced:

- Engineering Council of South Africa (ECSA) Learning outcomes 1, 2, 3, 5, 8, 9 and 10 are set for partial achievement
- Students work through an individual tutorial explaining all the relevant concepts, the step-by-step calculations for gears and information on how levers and pulleys work. The tutorial is completed with Professional Orientation lecturers and tutors providing assistance when needed.

- As from 2013, the tutorial has been augmented by a lecture explaining the challenging technical concepts. Additional notes on challenging concepts are made available on-line through UP's ClickUP system.
- Only since 2014, a pre-test, to evaluate students' pre-knowledge on gears, levers, pulleys and torque, has been completed on-line through UP's ClickUP system.
- Since the inception of the programme in 2010, a post-test on concepts and calculations to revise the information learnt, has been completed on-line by each student. The results of the post-tests are shown in Table 1.
- From 2013, a workshop followed the post-test with tutorials on MS Excel has then been facilitated. Knowledge gained from the workshop is, as a first step, applied when students are required to draw up an actual budget for their personal finances. This exercise serves as initial practice in the use of Excel to later draw up an estimated budget for the team for their LEGO crane.
- As from 2011, students hereafter have to produce a concept design with a focus on skills such as drawing, determining the gear ratio and speed, and also an estimated budget based on the number and cost of LEGO pieces used to build the crane as well as the cost of the land. This concept design has to be approved by a lecturer before the team can start building their crane. If the concept design is not approved, students have to reflect, rework and redesign it until it can be approved as a workable model.
- As from 2012, a workshop, making active use of small group discussion and practical application exercises, follow where group dynamics and effective communication in teams are addressed. As part of conflict management students are given scenarios in which they have to role play in order to practice the use of I-messages instead of you-messages, and assertive behaviour instead of aggressive behaviour
- Also from 2012 onwards, before allocating leading responsibilities to the various members of the team, students' knowledge gained in a workshop on Learning Style preferences previously conducted is refreshed. In this workshop students were given the opportunity to complete the Index of Learning Styles (ILS) Questionnaire developed by Felder on line (http://www.engr.ncsu.edu/learningstyles /ilsweb.html). The different learning styles were then explained pointing out advantages and challenges of each. In the LEGO project students are again asked to compare, in their teams, their various learning styles focusing on the strong and weak points of each style. Based on the comparison, they then decide which team member should take responsibility for each of the following roles: Overall project manager, Financial manager, Design manager, Administrative manager and Technical manager.

- Finally, based on the approved design, the teams can start building their cranes using the LEGO set.
- Each team receives two opportunities during the construction of the crane to test their crane while picking up increasing amounts of weight. Improvements on the design can be done if necessary. The minimum weight set as goal to pick up before the competition begins is 2 kg.
- In the final competition a starting weight of 2.5 kg is used.

2.2 Direct practical results of the LEGO project

Positive results from the project have been noted during all four stages of CDIO. In this section, specific reference will be given to three stages namely: Conceive, Design and Operate. Descriptive statics of pre-test and post-test scores and weights lifted from 2010 to 2014 have been analysed using statistical analysis software (SPSS, version 22).

2.2.1 Conceive stage

Post-test (2010 - 2014)

Results of post-tests written after doing individual research, completion of a tutorial and attending a lecture from 2010 to 2014 are shown in Table 1. The mean percentage in 2010 is the highest of the five years. There seems to be a downward trend in mean percentages from 2010 up until 2013, with the mean percentage for 2014 rising to 50%. This sudden rise in mean percentage could be a result of the effect of the pre-test introduced in 2014.

Table 1: Descriptive statistics: Post-test results (2010-2014)

	N	Minimum	Maximum	Mean	Std. Deviation
LEGO post-test (2010) [%]	254	9.1	100.0	59.986	17.0606
LEGO post-test (2011) [%]	330	9.1	90.9	52.452	17.4953
LEGO post-test (2012) [%]	297	16.7	78.3	48.603	12.4135
LEGO post-test (2013) [%]	199	10.0	90.0	47.571	14.2476
LEGO post-test (2014) [%]	203	12.9	88.6	50.155	12.0791

Pre- and Post-test (2014)

Only in 2014, a pre-test was written by students using their pre-university knowledge. After undertaking research activities on gears, levers, pulleys, torque and tower cranes, completing a group tutorial and the lecture, a post-test with the same level of difficulty as the pre-test was written. As results in Table 2 show, there is a marked increase from the pre-test to the post-test. From as low a mean as 37%, after research, a mean of 50% was recorded. The standard deviation for the post-test was also lower than the pre-test. This could be an indication that the research played a key role in knowledge gathering.

Table 2: SPSS Descriptive Statistics Output: Pre- and Post-Test Results in %

	N	Minimum	Maximum	Mean	Std. Deviation
LEGO pre-test (2014) [%]	203	.0	80.0	37.307	17.9988
LEGO post-test (2014) [%]	203	12.9	88.6	50.155	12.0797

2.2.2 Design stage (2011 – 2014)

Approval of the initial design before teams could start building their cranes resulted in re-working and re-thinking of the design at the start of the project. Real-life exposure, while building the crane, also showed the team what worked or not in their initial design. Consequently they could re-work and re-think the design again, and adapt it to suit their team's needs.

2.2.3 Operate stage (2010 – 2014)

In 2010, there were 85 groups. The number of teams increased to 111 in 2011, reducing to 60 groups in 2012, 63 in 2013 and 46 groups in 2014. The weights picked up by the teams are shown in Table 3.

Table 3: SPSS Descriptive Statistics Output: Weights (2010 -2014)

	N	Range	Min.	Max.	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Year 2010	85	5.535	.075	5.6100	1.96894	.152439	1.405416	1.975
Year 2011	111	7.100	.600	7.700	2.39685	.145945	1.537623	2.364
Year 2012	60	11.325	1.175	12.500	3.93208	.294198	2.278850	5.193
Year 2013	63	9.700	.000	9.700	3.43254	.287647	2.283128	5.213
Year 2014	46	12.100	.000	12.100	1.73370	.315080	2.136977	4.567

In 2010 an average weight of 1.97 kg was picked up. In comparison, in 2011 - when the CDIO framework was introduced - an average weight of 2.39 kg was picked up. In 2012 this average increased to 3.93 kg. In 2013, an average of 3.43kg was recorded. In contrast, in 2014 an average weight of 1.73 kg was recorded.

This low average for 2014, could be attributed to wear and tear of the following LEGO parts that have not been replaced since 2010:

- Electrical motor
- Axles
- Gears

The maximum weight lifted increased from 5.61 kg in 2010 to 7.70 kg in 2011 and finally to 12.50kg in 2012. It is clear that the maximum weight lifted more than doubled from 2010 to 2012 even though the exact same LEGO sets were used to build the cranes. The highest weight for 2014 was 12.1kg.

2.3 Student feedback on the LEGO project

In each stage of the CDIO framework, teamwork is empirical. During the design stage of the project, although there is a design manager, all team members have to contribute to the overall design of the crane. This shows just how important it is for the team to work as a unit. Although the teams generally struggle with teamwork skills in the Implementing stage because some team members try to dominate the process, this is set right when the first test of the crane invariably fails and the more passive team members start getting more actively involved. Finally all team members are involved in the completion of the project to the best of their abilities.

2.3.1 Examples of student discussions on Teamwork – extracts from student team Reports 2014

Team 6: Discussion Team work

The team tried their utmost best to perform as a collective unit and ensure that they achieve success. Achieving this success is seen as their common goal, which is in fact building the crane and achieving a podium finish in the overall competition and they were able to do so. The team have within the duration of the project displayed most of the characteristics of a successful team and this most importantly helped them achieve their primary common goal. The information below will show how the team collectively worked together during the different stages of the project, which are in a manner similar to those of a successful team.

Conceive stage - this stage involves defining what the customer needs and developing conceptual and innovative plans to achieve those needs while also keeping in mind regulations. This was a very interesting phase because in the very beginning everyone was not used to the team members that they were assigned to work with and all members were trying very hard to comprehend, visualize and impress the other members of the group at the task that had to be done even though we could all see that all of us had no ideas to begin with.

The team finally started to talk and express their ideas with regards to the project. All members were attentive listeners and that made it easy for people to come out with their views and thoughts.

Design stage - this stage focuses on creating the plans, drawings and all algorithms that describe the product and the process that will be implemented. This phase was the most challenging of all because most of the team members were people who prefer working alone and not generally people who work in teams. This was proven by the shy behaviour in the early phases conceive phase. So the members in the group wanted to rush the phase and get their delegated tasks and work on that rather than think on every aspect of the project and think about each and every single detail as a unit, but in the end things worked well in the phase because every single idea that came from each member of the team was accepted.

Implement stage – this phase refers to the transition between ideas and the product coming to fruition.

This was the most interesting phase because of the fact that we were all attentive listeners and the fact that every idea that each member gave rise to new ideas it made the phase become the most swift and enjoyable phase of them all. It was also interesting seeing how phase brought out the team work spirit within all the members. This can be said because once a member tried something different and that specific thing did not work there was no discouragement towards the member, for every success and failure was now a team success and failure, which was a complete mind set change from the conceive stage. In a nut shell every issue or misfortune was dealt with as a unit rather than put on an individual.

Operate stage – this stage uses the delivered implemented product to satisfy the customer.

The operating phase was challenging for it got the team to be frustrated and discouraged when the product was not delivering according to its expectations but it was not that demoralizing because it meant that the implementation phase was prolonged and because it was the most interesting part and the positivity in that lead to a successful operating phase. The crane that was created was unable to carry a mass of greater than 3 kg because one of the gears was loose.

Efficient communication between the team members was highly present. The team made use of modern day means of communication such as WhatsApp and emails. Delegation of tasks was made easy due to these communication mediums, the team members were able to work effectively also on weekends through these mediums."

Team 48

Figure 3 shows Team 48 brainstorming and working on the crane that was to be built. One of the Professional Orientation module lecturers took the photograph.

Team 48

Team work

“The team had a few hiccups during the time the spent together, but tried to overcome these nevertheless. In relation to the CDIO stage of the LEGO Project, the team worked in the following manner:

- Conceive Stage: All the team members were allocated a certain component, which included gears, pulleys, torque, tower cranes and levers, to research and were also designated a role to play in the overall LEGO Project. There were no problems faced in this staged as the team worked harmoniously.
- Design Stage: During this stage, the team was divided into two parts, one worked towards answering the theoretical sections of the concept design, while the other part of the team drew the tower crane, which was to be built. The division of the tasks according to the learning style preferences worked well, seeing that the team managed to obtain exceptional feedback for the concept design.
- Implementation Stage: The main problems were faced during this stage. The design was not implemented well. The team may have underestimated the amount of work that would have to be put into actually building the tower crane. The times, during which things did not go according to plan, led to the team's slight disinterest in the LEGO competition. The consultation sessions were not used sufficiently during times of uncertainty and the final touches were done at the eleventh hour.

- Operate Stage: This stage occurred during the actual LEGO competition. In spite of the challenges faced, the team remained positive and encouraged one another during the competition day. However, due to the unstable tower crane, which the team built, it was unable to enter the completion by lifting the minimum required mass of 2.5kg. Although the team's spirit was dampened by this defeat, they took pride in the fact that they put a lot of effort and time into this LEGO Project as a whole.

The team generally worked well together, despite the challenges they faced. It is safe to say that friendships were built and the task of working with unfamiliar people trained them for future projects in the actual workspace once their careers have lifted off."

3. CONCLUSION AND RECOMMENDATIONS

Over the period 2010 to 2014, both students and lecturers have reported positively on the LEGO project. The implementation of the CDIO framework has contributed to the integration of the students' learning experiences as well as the development of personal and interpersonal skills. Although the authors' review of the LEGO project is also positive, and various adaptations to the project have been made over the past 4 years, the scholarship of teaching and learning is still encouraging continuing development of the project. Therefore, the following recommendations are made:

- Budget: In 2013 and 2014 each individual student's personal budget was not evaluated in detail due to time constraints. No direct feedback to students could therefore be given. This should be addressed in 2015.
- The final assessment in 2013 and 2014 focused on the technical report and also the maximum weight picked up by each team. A more holistic assessment rubric must be developed which should include optimisation of the budget, which crane could lift the highest weight with the least number of Lego pieces, and how each team's time could be used most effectively.
- Over a period of time, all materials - especially plastic - wear and tear, reducing the efficiency of the parts. It is therefore, necessary to replace LEGO parts such as the electrical motor, gears and axles in 2015.

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