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The Impact of the Product Design Process on Final Year Design Projects

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Impact of the Product Design Process on Final Year Design Projects

Abstract

In an effort to better prepare students for the workplace, many institutions incorporate design courses throughout their curriculum. The content and nature of these courses often vary across institutions. Some schools incorporate design courses into every year of their program, while others provide students with a single capstone design experience in the final year. While some institutions use problem based learning approaches, others use guided experiential learning to teach engineering design. Design courses also vary by the source of the projects. In some institutions, instructors design the courses while in other institutions; students propose their design projects. A recent trend has been the use of industry-led and service-based projects for capstone design courses. Projects often vary by team size and may consist of teams of one to as many as five members.

A review of the literature reveals that there has been considerable investigation into the techniques used to teach design. However, much less attention has been given to the assessment of the effectiveness of these techniques in enhancing students' design skills. This latter point is important, as it is the reason for the growing popularity of design education. This lack of assessment is due to the fact that design techniques are typically taught during the latter stages of the final year of the curriculum and often concomitantly with the students' final year capstone design projects. Therefore, students apply the skills as they are taught. The first time they often design on their own is in the workplace.

The institution under investigation offers a unique opportunity to study the effectiveness of teaching design skills to students in general and the design process in particular. At this institution, students are taught the design process in two courses across two semesters during the student's second year of study. The course content includes all aspects of the design process from problem definition to prototyping. In the first semester, the emphasis is on component design, while in the second semester, the emphasis is on system level design. In both these courses, students work in teams of three to four students to apply the techniques taught to solve design projects that have been defined by the instructor. Then in their final year of study, students work individually on yearlong projects that are provided by industry, an instructor, or by the students themselves. There is no teaching component. For these projects, instructors serve as engineering advisors and students are responsible for defining and implementing their projects. Therefore, the success of the projects depends on the student.

This paper will first assess the extent to which students in the latter final year course adopt and apply the design process skills that were taught in the second year course. It will then evaluate the impact that adoption of these techniques had on the success of their projects. To this end, the benefit of teaching the design process in the second year course can be determined.

1. Introduction

Although engineers perform a wide range of functions including research, test, analysis and development, design is the activity most associated with the engineering profession[1]. This is especially true for mechanical engineering. In mechanical engineering, as with other engineering disciplines, design is defined as the process by which a product, process or both are developed in order to satisfy a specific need[2-4]. While technical knowledge and competency is necessary for success, it is not sufficient as engineering designers often need to possess numerous other skills such as creativity, problem solving, visualization, communication, team-work and planning skills in order to obtain successful engineering solutions[2,5-7]. Many educators and practitioners acknowledge that while one only becomes an expert engineering designer through experience, it is desirable that new college graduates display a reasonably high level of competency at engineering design. In fact, it is now a requirement of many new managers[2]. This is also reflected in the program accreditation requirements of the Accreditation Board of Engineering and Technology (ABET)[8] and the Engineering Council[9], the two major international organizations that set accreditation criteria for engineering programs.

As a result, over the last twenty years, engineering departments have begun to introduce engineering design courses into their curriculum[1,10]. The main objective of these courses is to bridge the gap between theory and practice in order to allow students opportunities to develop those skills that will be necessary for their roles as engineering designers[1-2]. However, the teaching of engineering design has other advantages. One of the main advantages is that engineering design courses, especially at the senior level, more readily lend themselves to the teaching of higher level cognitive skills such as synthesis and evaluation than the traditional theory based engineering courses[3,6,11]. The other advantage is that engineering design courses allow students to develop design skills in a “safe environment”, where the risks are lower. Well designed engineering design curricula provide students with “multiple chances to fail” and hence hone their engineering design skills, thus making them better prepared and more confident for their future careers[4].

When engineering design was first introduced into curricula, it was thought that a single capstone design experience would be sufficient to provide students with the necessary exposure for practice. More recently, some educators have agreed with the previously mentioned need to provide students with multiple exposures to engineering design in order to achieve proper cognitive and skill development. As a result, some institutions have begun to provide students with “corner stone” engineering design experiences as early as the first year, with engineering design experiences provided in each successive year of study to the final year[2-3,10-11]. Others have maintained the traditional approach, as they believe that earlier design courses do not add as much value as the theoretical courses. Therefore, there is currently no agreement on the appropriate number or frequency of engineering design courses for a curriculum and there is a wide variety of engineering design curriculum across institutions[10].

The same is also true for the methods used and content of engineering design courses[1,10]. Some institutions teach the design process using a traditional lecture format. Others prefer to use case studies to teach some aspects of the design process such as ethics, legal considerations, and safety. Still others adopt experiential teaching methods such as problem-based learning or service learning activities to teach engineering design courses[3-4]. In the institutions that still have only one capstone experience, the engineering design process is sometimes taught alongside with the execution of the project. Howe[10] observed that in 2005, 55% of institutions offered a design course concurrently with the capstone project, while 22% of institutions offered the design course first and then the project in a subsequent semester. Furthermore, some institutions teach technical content such as machine component design or focus the design experience around a particular technology such as mechatronic devices or compliant mechanisms, while at other institutions, the teaching of the design process is completely decoupled from the teaching of technical content and the courses and projects are designed to take into account students' existing technical knowledge[10]. As for the timing and frequency of the design courses, there is also no agreement among educators on the best approach for teaching engineering design and it remains the job of the institution and more specifically the department to define its objectives for an engineering design education[1,10].

Due to the wide variety of engineering design curricula, it is important that institutions properly assess their engineering design programs and measure the effectiveness of the approaches that they are using in teaching engineering design. Proper assessments could not only be useful in gaining employers' confidence in graduates of the program, but they could also be used to highlight deficiencies in existing programs[12]. Several methods have been proposed for the assessment of engineering design programs including: (1) Interviewing alumni, (2) Interviewing the employers of alumni, (3) Obtaining the feedback of project sponsors and (4) Self-assessment[6,11-13]. Program self-assessments, which include the assessment of student design capabilities while they are still at the institution, are the easiest to implement for the purpose of short term and longitudinal studies. One method of program self-assessment is the evaluation of the effectiveness of teaching the design process on improving students abilities to achieve good results at design as evidenced by their success in capstone design projects.

In assessing the success of capstone design projects, either the design process or the outcomes of the projects are assessed[11-14]. Design process assessment focuses on determining the competency of students in applying those skills that are most useful to practicing engineers[6,11]. Creativity has been recognized as an important component of the design process and methods to properly assess creativity have been gaining increasing attention by engineering educators and researchers[2-3, 5-7]. Figure 1 summarizes the criteria most often used in the assessment of general design process skills and creativity. The assessment of outcomes is often based on the construction and quality of a working prototype[13,10,15]. However, in some instances, analytical "paper" designs and simulations are used for project assessment.

PROCESS DESIGN

- Problem Definition
- Planning and Process Management
- Conceptual Design
  - Idea Generation
  - Idea Evaluation
  - Decision Making
- Detailed Design
  - Analysis
  - Evaluation
  - Visualization (drawing, simulation)
- Implementation
  - Prototyping
  - Testing

CREATIVITY SKILLS

- Divergent Thinking
- Convergent Thinking
- Problem Finding
- Problem Formulation
- Problem Solving

Figure 1 Criteria Often Used to Assess Capstone Design Projects

Of the many approaches used to assess student skill levels at the design process and creativity, scoring methods are the most popular. They are preferred over point evaluation methods as they give a better reflection of student achievement at the various aspects of design than a single numerical grade[11-12]. Charyton and Merrill[5] proposed the Creative Engineering Design Assessment (CEDA) tool as an assessment instrument for measuring the creative design abilities of first year students. Shah *et al* [7] proposed several metrics for assessing divergent thinking skills at the early stages of the design process. Davis *et al*[11] and Trevisan *et al*[12] proposed standardized scoring metrics that not only test the skill level of rising juniors at the design process, but also their teamwork and communication skills. In all the previously mentioned approaches, design reports, designed devices, video recorded design sessions, and reflective essays have been found useful for assessment.

Although the assessment of outcomes and use of the design process have been identified as good approaches for assessing students' design capabilities, there has been much less research in this area than for the design process. Instead, it has been generally accepted that once students are knowledgeable about the design process, they will be successful in attaining good outcomes[11]. Other academicians are of the opinion that adherence to the tools and methods of the product design process inhibit students' productivity, and hinder their ability to attain success in their final year design projects[14]. In the 2005 survey, Howe[10] observed that 12% of programs did not consider the outcomes at all in their evaluation of capstone design projects. These mindsets often lead to the confounding of the assessment of the design process with project outcomes. There is a need to quantify the impact of the utilization of the design process on the outcomes of student projects, as this will be useful for justifying the emphasis that had been placed on the teaching of the design process. This research explored the extent to which student use of the product design process resulted in successful outcomes in their final year design projects.

In this research, student success at achieving good outcomes in their final year capstone design projects was compared to the extent to which they implemented the design process. The students would have learned about the design process in earlier courses. Success in achieving the outcome of the product design process is defined in two ways. Firstly, the quality of the prototype device is used to evaluate student achievement. In addition, the analytical "paper" design is assessed as an outcome of the project. This latter approach is being used to normalize for any challenges that students may have experienced in building their devices. The scoring method proposed by Davis *et al*[11] will be used to measure the extent to which the product design process was correctly implemented by the students. Finally, the results of the scoring matrices will be compared to the grades awarded by three independent examiners. Correlation indices will be used to compare the two.

A case study of the capstone design course in the department of mechanical engineering at an undisclosed university was used as a case study. The case study is applicable as the institution provided students with design instruction and multiple design experiences in previous courses. In their final year projects, students worked on self-guided, individual design projects. Therefore, it is possible to determine the extent to which they utilized the design process to achieve the objectives of their projects. Assessing their success in relation to their use of the product design process will therefore provide some justification for the teaching of the design process in earlier courses.

2. Description of the Engineering Program

The curriculum of the mechanical engineering program used as a case study had a continuous design thread. The program lasted three years. In the first year of the program students were introduced to visualization and manufacturing techniques, in addition to their fundamental engineering courses. Students were taught the fundamentals of the design process concurrently with the technical aspects of design over two semesters in the second year of the program. The focus of the first semester of this second year was on component design, while the second semester focused on system design. In each semester, students worked in groups to develop a design using the design process and technical skills taught in the course. Course assessments in each semester were based on exams, project reports and presentations, and teamwork. In the third year of the program, students demonstrated their competency in mechanical engineering design in individual capstone design projects that lasted two semesters. Faculty members proposed the majority of the projects. A few of the projects had industry sponsors or were proposed by the students themselves.

The institution offered students a range of options for their final year projects including research based projects, industrial case studies, design-build-and-test projects, and process improvements. The final year projects utilized for this study were of a design, build, and test nature. Students were expected to execute their design and demonstrate a working prototype by the end of the project. Faculty members served mainly in advisory and coaching capacities, as students had been taught the skills necessary to develop their own projects in earlier courses. The project deliverables consisted of two presentations and reports, which were submitted at the preliminary design phase and final design phases.

3. Approach

As previously mentioned, it had traditionally been assumed that once students attained high levels of achievement at the product design process, they will be successful at design, as evidenced by the successful execution of final year, capstone design projects. As a result, the assessment of student engagement in the product design process and their success in their final year projects were often confounded. The result of this is that sometimes students who were very good at applying the product design process but by some unfortunate circumstance were not successful in realizing the outcomes of their projects, were evaluated as being less competent designers than students who did not appropriately engage in the product design process but were successful in realizing a working device.

In order to determine the impact of the product design process on project outcomes, the assessment of success in final year projects, as measured by the attainment of successful project outcomes, are isolated from the assessment of the design process. Methods for assessing the outcomes of final year projects and the extent to which students used the product design process were required. Since appropriate instruments for assessing the outcomes of final year projects were not found in the literature, new assessment instruments were developed for this study. The scoring scales introduced by Dym *et al*[11] were used to assess the extent to which students properly utilized the product design process. The details of these assessment instruments are presented in Sections 3.1 and 3.2 respectively.

The assessment instruments were applied to fourteen final year projects, which were performed over the two-year period 2010-2011, with seven projects from each year. One evaluator assessed the projects. The Cronbach's alpha (α_C) was used to test the internal consistency of the scoring instruments[16-17] and *t*-tests were used to determine whether there were statistically significant differences between the two cohorts of students used for this study. Correlation indices were then computed for comparing the design project outcomes to student achievement at the design process.

3.1. Student Success at Achieving Outcomes

This study used two methods to assess student success at achieving the outcomes of their final year projects, (1) assessment of the designed device (*DD*) and (2) assessment of the analytical design (*AD*). These two outcomes based approaches evaluated the extent to which students were successful at engineering design. In addition, the final course grade was considered, as it also reflected the success attained in the course.

The first approach used for measuring student success, i.e. assessment of the device, not only assessed whether a device was developed, but also the quality of the device. The assessment instrument for the *DD*, which is given in Table 1, included consideration of the quality of construction, the performance of the device and the extent to which the device met target performance specifications.

Subcategory: Construction - Prototype is built and all components are securely attached							
	1	**2**	**3**	**4**	**5**	**6**	**7**
State	Incomplete; not constructed or many components are missing		Mostly complete; some major components are missing		Nearly complete; few minor components are missing		Construction complete, all components are provided.
Robustness	Propped, braced, taped, cannot judge - no comment		Extremely wobbly, many dangling parts, does not operate without intervention		A little wobbly; most components are securely attached; Needs occassional nudging or special conditions for stability.		Free standing, all components securely attached, no user intervention required
Appearance	Unacceptable, cannot judge - no comment.		Poor, many rough edges		Acceptable, a few rough edges		Professional, no rough edges
Subcategory: Functionality – Prototype operates and can perform the intended functions (qualitative)							
	1	**2**	**3**	**4**	**5**	**6**	**7**
Operation	Does not start / operate		Starts, but does not function		Operates, but requires adjustment		Functions without adjustments
Intent / Objectives	Not indicated		Alluded to		Stated		Unambiguously stated with explanations
Satisfaction	Not as intended or extremely different from intent		Occassionally as intended; Function obtained has a few similiarities to intent		Most times; Mostly as intended.		Always as intended; All functions meet intent.
Subcategory: Performance Specifications – Capability of the designed device to meet the quantitative performance targets							
	1	**2**	**3**	**4**	**5**	**6**	**7**
Comparison to Target and Final Specification	Not considered		Mentioned but not discussed		Discussed without evidence		Discused with supporting data
Quantity Considered	None		Few		Many		All
Satisfaction Degree	None		Few		Most		All

Table 1 Developed Device (DD) Scoring Scale

The second approach used for measuring student success at achieving project outcomes involved the assessment of the successful development of an analytical "paper" design. Table 2 gives the scoring metrics used for assessing the *AD*. The assessment included consideration of whether there was a thorough description of a final design, whether the final design was analyzed and the extent to which the analytical design met qualitative and quantitative target criteria. Since the projects spanned a range of expertise, the accuracy of the analysis was not assessed. However, there was sufficient information to assess the completeness of the analysis, therefore this was taken into consideration. This second analysis was performed to remove biases associated with the building of a working prototype that may have resulted from difficulties in construction and the sourcing of material in a timely manner.

Project grades (*GR*) were awarded based on the assessment of three faculty members, with a different group of faculty members assessing each project. One of the three faculty members was the student's project supervisor. The second assessor was a faculty member whose expertise most closely matched the student's project. The third faculty member served as a moderator who resolved any discrepancies associated with the grading of the two main examiners. The examiners assessed the student projects at two phases, at the end of preliminary design and then again at the end of the final design phase. At both phases, the assessments were based on project presentations and reports. The assessment instrument included a combination of process and outcomes based approaches and the extent to which it was administered varied by faculty members. Some common criterion evaluated by the faculty members included the quality of alternative designs, design selection criterion, detailed design, and device operation. Due to the wide variability and inconsistency in application, the assessment instrument is not reported. However, as the faculty had a wide range of experience with assessing student projects, the grades they awarded to the projects are also being used as another measure of student success.

Subcategory: Description - Includes a description of the structure (system, subsystem, components) and functionality of the final design							
	1	**2**	**3**	**4**	**5**	**6**	**7**
Completeness	No description provided		Many elements are missing		One or two major elements are missing		All systems, sub-systems and components are fully described.
Clarity	Extremely vague		General; Lacks detail.		A few details a missing; Mostly understandable.		Detailed; Fully comprehensible
Methods	No method.		Either verbal or visual method, but not both.		Both verbal and visual methods used, but do not support each other.		Verbal and visual explanations support each other.
Organization	Haphazard, random		Some structure; not logical		Mostly structured.		Structure enhances reader's understanding.
Subcategory: Analysis							
	1	**2**	**3**	**4**	**5**	**6**	**7**
Quality	No analyses. Only qualitative discussions		Few minor calculations / simulations.		Analysis for some major components and subsystems		Complete analysis of overall device performance.
Relevance	No influence on overall performance of major system or subsystems.		One or two minor components analyzed.		Relates to performance of major subsystems but not to the overall performance of the device. Needs more work.		Directly impacts overall device performance.
Subcategory: Performance Specifications – Capability of the designed device to meet the quantitative performance targets							
	1	**2**	**3**	**4**	**5**	**6**	**7**
Comparison to Target Specification	Not considered		Mentioned but not discussed		Discussed without evidence		Discused with supporting data
Quantity Considered	None		Few		Many		All
Satisfaction Degree	None		Few		Most		All

Table 2 Analytical Design (AD) Scoring Scale

3.2. Design Process

The design process scoring scale (*OP*) introduced by Davis *et al*[11] is adapted for this study. This scoring scale assesses the application of the design process along seven dimensions including information gathering, problem definition, idea generation, evaluation, decision making, implementation and process development. Each of these categories was further divided into several subcategories which are shown in Table 3. The reader is referred to the original paper[11] for details of the scoring scale.

The Davis *et al* scoring scale[11] was modified in order to meet the objectives for this research. More specifically, the changes made to the Davies et al scoring scale are as follows:

1. The Davies *et al* scoring scale contained a section that assessed the ability of students to execute their design through the development of a device. However, since the primary objective of this research was to decouple the assessment of the design process from the project outcomes, this section, the "Implementation" section, was removed from the Davies *et al* scoring metric.

2. The Davies *et al* scoring scale contained metrics that assessed how well students worked together to generate their conceptual designs and to make decisions. These sections, which were referred to as “Climate” and “Participation” respectively in the Davies *et al* scoring metric, were not applicable when an individual student executed the design process. As a result, the “Climate” and “Participation” metrics were removed from the original scoring scale.

Information Gathering	Sources	Number and type of sources, including client
	Quality	Student judgment about validity of information from the source
	Frequency	Number of times the students sourced information during the process
Problem Definition	Client Needs	Awareness and prioritization of customer needs (design requirements)
	Requirements	Number and variety of customer needs generated
	Definition	Specificity, measurability, and categorization of the customer needs
Idea Generation	Climate	Ability to create an environment that supported creativity
	Methods	Number and process of tool utilization in developing design alternatives
	Types	Types of ideas generated, solution and. process
Evaluation	Issues	Number and type of considerations, technical, financial, life-cycle considered in evaluating alternatives
	Analysis	Tools used, qualitative and quantitative for evaluating alternatives
	Results	The degree to which the evaluation results were interpreted
	Participation	Number and extent to which team members participated in the process
Decision Making	Criteria	The design requirements / customer needs considered for selecting a final design
	Process Tools	Number and type of tools used for selecting a final design
Implementation	Deliverables	Delivery of project outcomes within time and budget
	Requirements	Number and degree of sastisfaction of target specifications
Process Development	Elements	Extent of application of the process development process
	Management	Evidence of and documentation of the management of the process

Table 3 Subcategory and Criterion for the Davis et al (2002) Design Process (OP) Scoring Scale

4. Results

The scoring scales presented in Section 3 were used to assess the outcomes and design process of fourteen final year design projects. The assessment of project outcomes was based on the development of a working prototype, i.e. designed device, and on the “paper design”, i.e. analytical design. Evidence of the number and frequency of utilization of various design process tools were used to assess the design process. Course grades were also used as a measure of student success. For each project, scores were first awarded for each subcategory and then total scores were computed within the corresponding subcategory. The subcategory scores were then aggregated to compute the final overall score. *DD* was the total score for the designed device, *AD* was the total score for analytical design, *GR* was the grade earned in the course and *OP* was the overall design process score. Percentages were then computed for each assessment method. Correlation indices to determine the relationship between success indicators, *DD*, *AD* and *GR* and achievement levels at the design process, *OP*, were then computed.

4.1. Evaluation of Assessment Methods

New scoring scales were developed to assess the designed device and the analytical design, while an existing scoring scale was used to assess the design process[11]. The values of the Cronbach alpha, α_C, for the scoring scales provided in Tables 1-3, were as follows: $\alpha_C(DD)$ =

0.76, $\alpha_C(AD) = 0.72$, and $\alpha_C(OP) = 0.85$ respectively. These values for α_C were all within the acceptable ranges, indicating that the scoring scales had good internal consistency.

Consideration was also given to whether there were any significant differences between the scores of the two groups of students that could affect the results. Recall that there were seven projects in each year. The results for the t-tests given in Table 4 indicate that there was no statistical differences in *DD*, *AD* and *OP* for $t(12)=2.68$ at $p=0.02$, for the two cohorts. As a result of the high level of consistency across the two-years, the project reports of the two cohorts of students were treated as a single data set.

Metric	*DD*	*AD*	*GR*	*OP*
***t*-statistic**	0.14	0.13	0.58	0.33

Table 4 Results of t-tests for Determining Differences in Results Between 2010-2011

4.2. Evaluation of the Impact of the Design Process on Student Success

Correlation indices for the outcomes, design process, and grades are given in Table 5. A fairly strong correlation of 0.54 was obtained between *DD* and *AD*. The relationship between *OP* and *GR* was also fairly strong, with a correlation value of 0.51. *AD* and *DD* had weaker relationships of 0.38 and 0.43 respectively to *OP*. The correlation between *AD* and *DD* and the grades earned by students were even weaker, attaining values of only 0.26 and 0.08 respectively.

The effect of the product design process on the project outcomes can also be determined by comparing the results in each category. Table 6 compares the maximum, minimum and average percentage scores for *DD*, *AD* and *GR* for students who scored above average on *OP* to those who scored below average. These results indicate that the average *GR*, *DD*, and *AD* scores of students who had above average *OP* scores were 22%, 20%, and 14% higher respectively than those who had below average *OP* scores. In addition, the maximum and minimum scores for *DD*, *AD*, and *GR* are significantly higher for students who had above average *OP* scores.

	DD	***AD***	***GR***	***OP***
DD	1	0.54	0.08	0.43
AD		1	0.26	0.38
GR			1	0.51
OP				1

Table 5 Correlation of Outcome to the Design Process

	OP **Above Average**			***OP*** **Below Average**		
	DD2A	***AD2A***	***GR2A***	***DD2B***	***AD2B***	***GR2B***
AVERAGE	43	36	72	35	30	63
MAXIMUM	63	50	78	46	43	71
MINIMUM	30	15	66	23	22	42

Table 6 Scores for Outcomes for Students Who Scored Above Average on the Product Design Process

5. Discussion

5.1. Significance of the Design Process

As indicated in the Introduction, Section 1, engineering design educators have been advocating the importance of teaching the design process as the acquisition of design skills by students better prepares them for the practice of design. The results presented in Section 4.2 provide evidence that students who achieve a high skill level at the design process have better capabilities at executing design projects, as demonstrated by their improved ability to successfully produce design deliverables.

The results in Table 5 indicated that there was a fairly high correlation of 0.54 between *AD* and *DD*. However, the correlations between *AD* and *OP* and *DD* and *OP* were much weaker with values of 0.38 and 0.43 respectively. These results suggest that while the realization of a good analytical design may have some influence on the attainment of a successful designed device, this may not have been due to the implementation of the design process. This result is counterintuitive and requires additional investigation.

Furthermore, the results in Table 5 indicate that while there was a fairly strong correlation of 0.51 between *GR* and *OP*, the correlations between *GR* and *AD*, and *GR* and *DD* were weak, with values of only 0.26 and 0.08 respectively. These results suggest that the faculty placed a much higher value on the implementation of the design process than on the actual outcomes of the projects. This result is not surprising as it is consistent with the objective of such a course, the teaching of the design process. However, these results do bring to the fore the need for paying closer attention to what students actually produce as part of their design projects.

5.2. Limitations

While this study provided a first step towards quantifying the impact of the design process on the outcomes of final year projects, there were a few limitations in this study. The limitations mainly involve the assessment of the designed device. The study was not conducted at the time that the students executed their projects. Therefore, only project reports were available for the assessment of project outcomes. As a result, it was not possible to assess important factors such as the originality and complexity of the designed device.

Originality was not assessed, as it would have required domain specific knowledge. Due to the wide range of subject areas that the projects covered, the investigator was not able to provide a good assessment of this factor. The drawback of not assessing originality is that an important measure of students' actual capability to design may have been missed as some students may have simply adopted existing designs. The latter of course is much easier to achieve. Therefore, it is recommended that this be included in evaluating the designed device in future studies.

The projects assessed varied widely in their complexity, from the design of simple structures to the design of complicated solar devices. The complexity level of projects may have affected the ability of students to both realize the project deliverables and successfully execute the design process. The use of complexity measures would have given an indication of the potential difficulty in achieving the final design outcome. It is recommended that projects be either normalized for complexity or that complexity measures be explicitly taken into consideration in the future.

6. Conclusion

This research investigated the impact that implementation of the product design process had on students' abilities to achieve successful outcomes in their final year projects. The outcomes considered were the development of a working device and the production of an analytical "paper" design. Existing scoring matrics were used to assess the design process. Since no suitable instruments were found, new scoring matrices were developed for assessing the quality of the designed device and the analytical design.

The design program at an international institution was used as a case study. The program used had a continuous design thread throughout its curriculum. The design process was taught in semesters prior to which students engaged in individual, yearlong final year design projects. The scoring metrics were used to evaluate the reports of design projects that were conducted over a two-year period.

Correlation indices were used to relate the results of the project outcomes to student level of achievement at the design process. Fairly weak correlations were found between students who demonstrated high skill level at applying the design process and the realization of quality designed devices and analytical designs. The results were unexpected as they indicate that application of the design process had little impact on students' abilities to be successful at executing design projects. The results also indicated that demonstrated capability at engaging in the design process was more highly valued than the achievement of project outcomes in the awarding of student grades. The results provided evidence of the importance that faculty place on the teaching of the design process. They also provided evidence for the usefulness of assessing the outcomes in measuring student success in their final year projects.

In the future, it is recommended that this study be extended to a wider range of institutions and over a longer period. In addition, more persons including industry practitioners should use the new instruments proposed in this study in order to provide further verification and validation. Finally, another proposed area of future work is the inclusion of originality and complexity measures in the assessment of the proposed device.

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