AC 2010-2142: DESIGN OF AN INSTRUMENT TO ASSESS UNDERSTANDING OF ENGINEERING DESIGN

Kristen Facciol, University of Toronto

Lisa Romkey, University of Toronto

Jason Foster, University of Toronto

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Division of Engineering Science, University of Toronto

Abstract

Engineering design education is an important element of any undergraduate engineering curriculum. It is also an element undergoing constant evolution, reflecting the rapidly evolving needs of engineering industry and academia. Engineering graduates are expected to contribute effectively as members of multidisciplinary engineering design teams. Enabling this success requires that engineering design educators develop an understanding of the diverse disciplinary perspectives on engineering design and of the evolving perspectives of their students.

This paper first describes the disciplinary perspectives that emerged as a result of some preliminary research on engineering design education, and then describes the development of an instrument for evaluating individual understandings of engineering design. Disciplinary perspectives were explored through interviewing the instructors of four capstone design courses in different engineering disciplines within a large engineering Faculty. Each instructor was asked about their instructional history, the requirements and expectations of graduates from their respective engineering undergraduate program, and their past attempts to understand course outcomes.

Although instrument testing is still required, the instrument developed can be presented to a group of students at the beginning, mid-stream and completion of their capstone design course. It can also be used to track changes in students' perceptions, as well as the influence that a particular discipline may have on an individual's understanding of engineering design. Course instructors will then be able to identify which aspects of their courses are most influential and which require more development.

Recognition of the design methodologies and expectations within specific engineering disciplines is an important first step in developing a curriculum that enables engineers to work across those disciplines. An instrument that supports the analysis of a Faculty's progression towards this end is a valuable addition to the engineering design educator's toolbox.

Introduction and Motivation

The goal of this project was to design an instrument to assess the student perception of engineering design and how it evolves through courses and over time. The instrument design was informed by examining four capstone design courses from across the Faculty of Applied Science and Engineering at the University of Toronto; more specifically, from the disciplines of Chemical, Electrical & Computer, Industrial and Mineral Engineering. The instrument was also informed by the expectations of an engineering graduate, as outlined by both the accreditation board and the university, as well as past attempts in the literature and industry at establishing similar forms of assessment. In the longer-term, this instrument will be used to assess and compare student perspectives on design from across engineering disciplines.

Beyond gathering information that will inform instructors of the development of their students' thinking, and how what they have taught is learned by an individual, disciplinary variants can be recognized at the Faculty level through widespread use of the instrument. It is also hoped that the tool will provide an outlet for the unification of themes across disciplines, allowing for a more streamlined approach to multi-disciplinary team development in future practices.

Method

Four capstone design courses were selected to represent diverse Engineering disciplines. The instructors of these courses were interviewed about their course and approach. The purpose of the interviews was to gain insight to the perceptions and experiences of the professors. The goal of each interview was to identify and describe five important topics:

1. Engineering Design Perceptions (including the identification of an engineering design process);
2. The Impact of Experience (whether or not they worked in industry and how it changed their perceptions);
3. Course Objectives (what the professors most want the students to learn);
4. Methods of Instruction (lecture, tutorial or problem-based); and
5. Course Outcomes and the Qualities of an Engineering Designer.

The following section of the paper explores the discplinary perspectives, as discovered through the interview process, of the four instructors.

Results of Professiorial Interviews

The primary focus of these investigations serves to identify what models and methods are currently being used in the design classroom. Each professor was interviewed, and later provided with the results of the interview for verification.

Chemical Engineering

This course is an exercise in the design of processes and products used in the chemical engineering industry and an opportunity to apply the theoretical knowledge from the students' previous years of study. Ideally, by the end of the course, the students should be able to:

- Design an entire system;
- Recognize inconsistencies between a design and its requirements; and
- Discuss the benefits of one design solution over another.

These outcomes are met through the preparation offered by a series of courses that gradually introduce the necessary knowledge and skills for the capstone design course.

The aim of the course is to introduce students to a way of thinking that allows them to discuss theory within their practice and to understand why certain decisions are made. An important element of the course is reverse engineering; this teaches the students to look at a final product and draw conclusions about the decisions that were made. This understanding comes from their ability to analyze conceptual problems, make informed decisions, look at a problem in its entirety, and understand differences in processes and results.

It was the experiences of the professor in the chemical engineering industry that resulted in him teaching design at the Faculty, and using the approach that he does to teach the course. The instructor believes these methods and practices cannot be taught unless one has experienced them first-hand.

The professor of the design course in chemical engineering has described the design process as a simple four block diagram that presents the major phases that occur during design; this is shown in Figure 1. According to the professor, this process is a classic total quality management approach because of its repetition of states and this professor has emphasized the importance of iteration. Its use throughout the course is strongly encouraged.

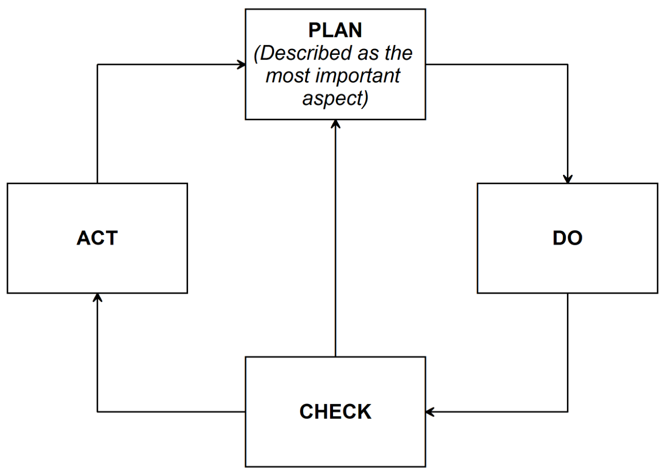


Figure 1: Engineering Design as Perceived by the Professor of a Chemical Engineering Course

Electrical and Computer Engineering

This design course introduces the undergraduate students to a project far bigger than what they have previously encountered in their engineering education. The project is completed in teams of students, similar to practices they would encounter in engineering industry. The learning objectives of this course are process-oriented; the professor examines the process the students have followed and how they got to their end point. The professor believes that the process of the design is even more important than whether or not the final product works. In this particular project, the professor encourages students to break down a problem, test it incrementally, and eventually put it back together once these individual components are functional.

The course allows for frequent engagement with students in a studio session that promotes discussion of the progression of their work. Laboratory time is used to introduce students to the task of system debugging, which is recognized as an important aspect of system design. No record is required, but they do keep weekly milestone reports that detail what was supposed to be done, what was actually done, what modifications must be made, and what will be done next. This reflection is an important aspect that is not always realized by students, but an important part of the experience is looking back and realizing that you can not always do as much as what was initially anticipated.

This professor's involvement in the design course is a natural consequence of his years of experience in design. Beginning with formal exposure in undergraduate courses, the professor has gone on to be involved with very design-oriented projects and research as well as involvement with industry. Their industry experience has been beneficial, as it was there that he was exposed to industry practices and large-scale design projects. One lesson learned that the students are now taught is that there is a strong need for a formal design process and that they must learn to break large projects down into smaller components.

The students taking this course are presented with the engineering design process as shown in Figure 2. The diagram captures the process at a high level, but this process is still considered more specific to electrical and computer engineering than any other engineering discipline. Although only two explicit feedback loops are shown, there are several cycles of iteration within each of the individual steps and feedback between all elements of this design process. This process necessitates a thorough understanding of the problem. This understanding is driven by requirements and constraints. The final result is the reduction to some implementation that meets those requirements and constraints.

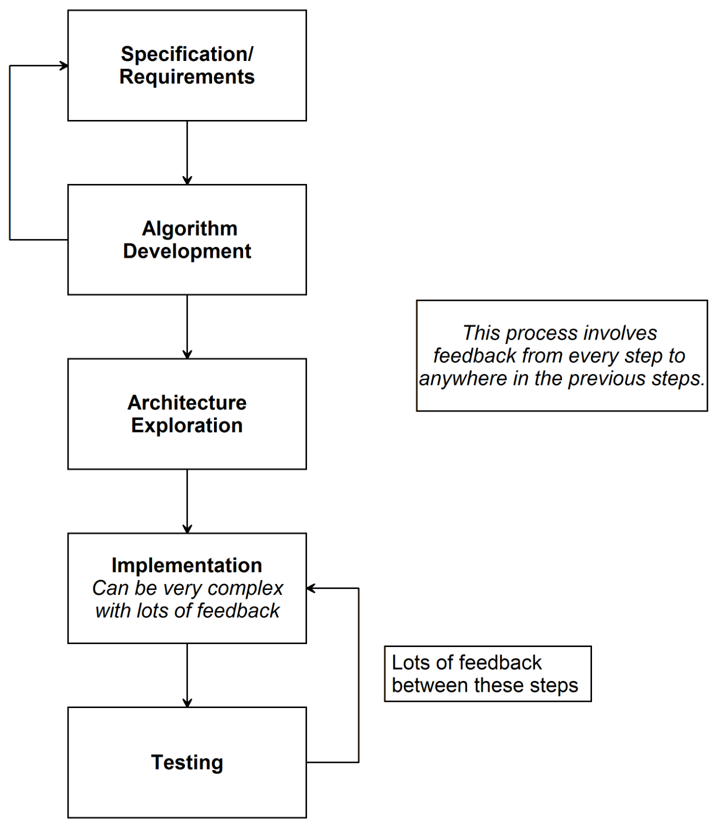


Figure 2: Engineering Design as Perceived by the Professor of an Electrical and Computer Engineering Course

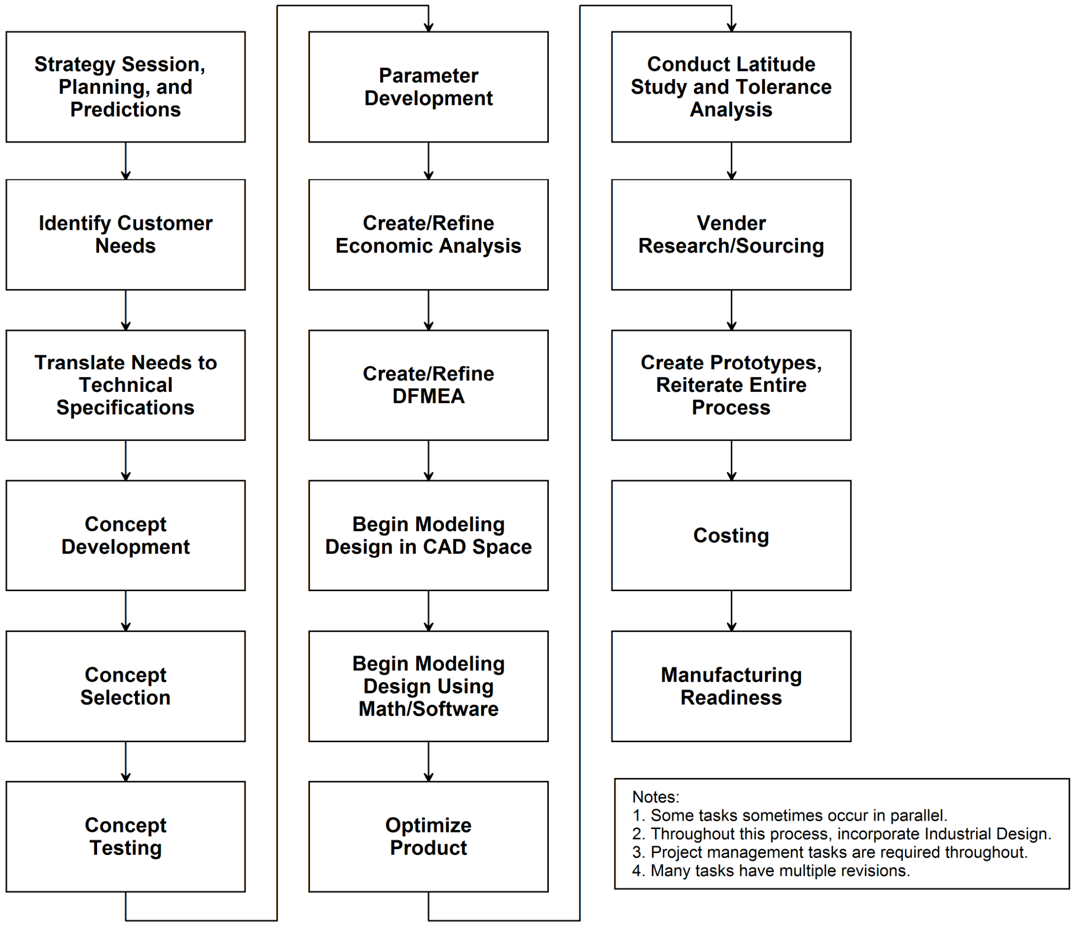
Mechanical and Industrial Engineering

This product design course focuses less on specialization and more on introducing students to a number of different topics pertaining to engineering design so that they “get their hands wet in every subject” prior to entering the industrial sector. Ideally, this will result in the students having a well-rounded understanding of product development. The students work in teams and are presented with a number of tools and anecdotes from the professor’s personal experiences that can be used throughout the process, and it is up to them to determine which will be most useful; this allows for flexibility and the ability to customize the engineering design process to meet the specific needs of the customer. This course closely replicates industry procedures and strongly encourages the importance of constant communication between members of the team and between the team and client.

Ultimately, students will realize at the end of this course that to be an engineering designer one can not purely be an engineer; they require a creative mindset, the ability to work in a team, the ability to think analytically and remain open-minded, an understanding of experiment design and risk mitigation, and experience with costing. Engineering design is a multidisciplinary process.

The identified process is a result of this instructor’s ongoing industrial involvement and wealth of experience in both engineering and business as a design engineer as well as a financial engineer. It is his experience in these areas that has resulted in a Faculty position involving a combination of the two. He also believes in the importance of design and economics being identified as a single entity in the realm of product design.

The instructor of this upper-year design course in Mechanical and Industrial Engineering has detailed a design process that is mostly linear, where one step must be completed prior to advancing to the next one. However, iteration has still been recognized as an important concept. The process also identifies the open-ended nature of engineering design and the ability to take a broad initial topic and introduce specifications that result in a final concept. In order to reach this point, the process becomes interdisciplinary; crossing business, engineering and industrial design.



Note: DFMEA (Design Failure Mode Effects Analysis)
Figure 3: Engineering Design as Perceived by the Professor of a Mechanical and Industrial Engineering Course

Mineral Engineering

The course under analysis is the second half of a two-part, year-long course that requires the students to bring a major mining project into the phase between scoping and pre-feasibility testing. The project involves design, optimization, detailed analysis, scoping, equipment and personnel selection. Social and environmental aspects are also briefly introduced. By the end of the course, the students have a general idea of the economics involved in a large-scale project through the use of cash-flow documents, and a thorough understanding of the preparation of a proper engineering proposal. Although the project is very comprehensive, and mirrors current industry standards, the professor “wouldn’t consider any of them an engineering designer”, but the students have successfully completed step one of a multi-stage design process used in the real world.

The projects that the students are dealing with are quite large and are completed in groups of three to four so that each person takes on a single aspect of the overall project. The course is run with the high involvement of members of the mining industry; they provide software training and come in to speak to the class on a number of different issues that the students might encounter throughout the project. The class size is small, allowing for considerable consultation with the course staff on the entire process. Using industry standards, the students are guided due to the modularity of the task as well as the requirement for preceding steps before they can advance to the next one. However, within each of these steps, a lot of looping is required and analyses must be rerun frequently in order to obtain a very particular output.

This professor's involvement in the mining industry has been extensive, and he continues to remain involved through various projects as a consultant. When asked how this has affected the manner in which the course has been taught following any experience gained in the industry, his response was: "I don't think I could have done it without it…I don't know how you teach things you haven't done." The benefits if this industrial experience are also apparent in those students who take on a Professional Experience Year (PEY) position or who work during the summer; it is only through these experiences that one gains a better understanding of the pragmatic side of the industry.

The process identified by a professor in the Mineral Engineering department is a simple four-block model (Figure 4) that can be applied to most engineering disciplines and emphasizes the importance of iteration. This process does not necessarily yield a single solution and involves optimization while looking at safety, efficiency and cost functions.

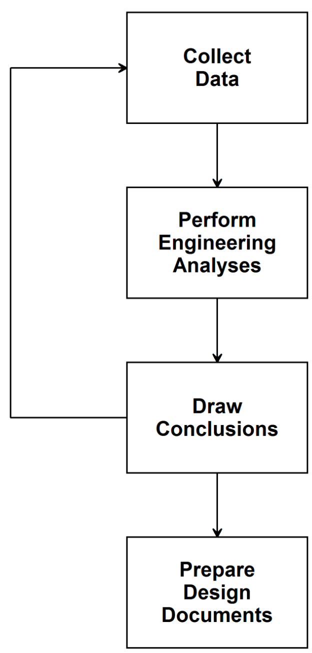


Figure 4: Engineering Design as Perceived by the Professor of a Mineral Engineering Course

Summary

Although four very distinct engineering disciplines were compared, there were a number of unifying themes that surfaced allowing for the generation of a global perspective on engineering design that could be used for instrument generation:

1. All professors agreed on basic elements of engineering design and the need for a process that involves iteration. These processes outline movement from problem specifications to a final design that have specialized intermediate steps depending on the engineering discipline.

2. Realization of the need for an iterative process has been a result of industrial experience and involvement in large-scale projects; this was common to all professors. Their experience has benefitted their teaching in the course.

3. Performance of the students in design courses following their PEY was better than students who did not have any work experience. For those students who lack this experience, the objectives of the courses are central to exposure to the pragmatic side of the industry.

4. Students are introduced to an engineering design processes by presenting them with a large project, or aspects of a large project, to be worked on or analyzed by a student or team of students.

5. Methods of instruction have also been found to be relatively uniform in these capstone courses, with information and basic concepts presented in lecture but also an opportunity for students to work and interact with course instructors during tutorial sessions.

6. Although the course outcomes and engineering designer qualities do differ depending on the engineering discipline, the assessments within the course look at the students' overall abilities to engage in discussion about design, prepare presentations and engineering documents, analyze various processes and products, and in some cases, provide a solution to a problem posed at the beginning of the course.

Overall, differences in the courses, and therefore disciplines, can be realized at lower levels, while it is still possible to develop a central idea of engineering design education across the Faculty.

The Instrument

The purpose of this project was to design an instrument that would effectively measure the student perceptions of engineering design at the completion of an undergraduate course in engineering. The final instrument, found in Appendices A.1 and A.2, is composed of a series of short-answer questions and skill/topic lists populating two tables that will help in determining these perceptions. The design of the instrument came from the culmination of and reflection on information from a number of sources.

The design objectives for this instrument were to look at engineering design as a whole from several perspectives and determine unifying themes and elements from a number of sources. The instrument then served to look at the conceptions of the students and to analyze and compare these to the overarching ideas identified by their professor and across the various engineering disciplines. The instrument does this by looking at explicit definitions of what the student perceives the engineering design process to be, as well as implicitly identifying the resulting skill set and beliefs of the student. Unfortunately, a method to effectively identify the process that was implemented by the student is difficult but is an important course outcome.

Design Process

The instrument design was reliant on a collection of sources. It included elements from the interviews held with the professors, existing curricular requirements for engineering programs, items identified as crucial elements of engineering design within the literature, and past instruments and concept inventories.

Contributions from Interviews

The interviews with professors across a variety of disciplines, helped to generate an initial collection of common elements from different engineering design processes used across the Faculty. The most significant information realized as a contributing factor to the design of the instrument were the responses pertaining to the course outcomes and expected qualities of an engineering designer. Unifying themes were identified as discussed in the summary of the interviews above, and used in the construction of the instrument.

Contributions from Curricular Requirements

In the Faculty under study, there are three sets of requirements for an engineering degree awarded at the baccalaureate level: Degree Level Expectations for Graduates Receiving the Degree of Bachelor of Applied Science (BASc) as set by the institution, Accreditation Criteria and Procedures as defined by the Canadian Engineering Accreditation Board (CEAB), and Criteria for Accrediting Engineering Programs as defined by the Accreditation Board for Engineering and Technology (ABET). The curricular requirements outlined in these documents helped in populating a list that would be used to determine the perceived qualities of a good engineering designer, as well as the elements in an engineering design curriculum.

Since all of the courses under analysis are a part of the same Faculty, it is important to look at the degree level expectations that apply to each of the disciplines in question[1]. The foci of engineering design within the curriculum involve courses with substantial design in their first three years and a capstone design course in their senior years, that include both group design and independent work elements. In all courses, teamwork, communication, and decision-making are major topics that are dealt with throughout the term. Ideally, the courses involve an application of knowledge and require students to evaluate the appropriateness of various approaches to analyze and solve the design problem, while devising and sustaining arguments for their design.

This structure is dependent on the CEAB requirements[2] which dictate that the curriculum must culminate in a significant design experience which is based on the knowledge and skills acquired in earlier course work and which preferably gives students an exposure to the concepts of team work and project management.

A number of past instruments generated for use in the American curriculum, as well as alternative methods of evaluation used in Canada, have been based on the list of program outcomes shown below, published by ABET for applied science and engineering programs.

Criterion 3. Program Outcomes[3]:

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

These outcomes provide a comprehensive list of the qualities students should possess to be considered engineering designers at the completion of their undergraduate degree and are important to consider for instrument design.

Contributions from the Literature Review

An important observation that has been made as a result of an extensive literature review is that engineering design cannot be identified by a single process, and that if it is presented to someone in a certain form, even then it is still open to interpretation. Although at a high level these processes can be unified, it is still important for the designer to adjust it to meet their needs. This realization prompted the inclusion of a question that would allow the students to show this personalization of engineering design, allowing the assessor to determine the most important aspects of engineering design as communicated by the student. This expression allows for a direct comparison to the perceptions of the instructor and an understanding of which topics are emphasized throughout the course.

Some of the literature identified the importance of looking at what the students were learning relative to the learning objectives of the course and what they were learning through their experiences in the course. Although these could not necessarily be identified for each student, the instrument results can be compared to the course objectives mentioned by the professor to examine this.

The literature review was used significantly in the culmination of the lists of engineering design curriculum elements and the qualities of a good engineering designer, as found in the instrument. The final lists were determined based on the frequency and importance of certain terms within the literature, which helped to narrow down the list as well as determine other items that had been missed.

Contributions from Past Instruments and Concept Inventories

Unfortunately, there are very few examples of instruments or concept inventories that employ a method of assessing engineering design conceptions, especially within the undergraduate curriculum. It was the realization of this gap that encouraged the direction of this project.

Davis et al. introduced a method of measuring learning outcomes for engineering design education that is based on the establishment of learning outcomes at two points throughout the curriculum, then defining performance indicators, lists of evidence, and scoring scales. The assessments are more thorough in upper years, with higher expectations for these students as they advance through the program[4]. This will be important for future applications of the instrument when looking at slight modifications that can be made to analyze student growth.

Okudan et al. have done the most thorough analysis of the assessment of learning and its retention in the engineering design classroom. Their paper details the development of an engineering design knowledge assessment instrument which will ultimately serve to define the environment and conditions that are most conducive in teaching engineering design concepts. It measures the impact of pedagogic changes and supporting classroom materials on student learning[5]. Although the goal of the instrument generated by this research is not to look at the learning environment, there were important areas of discussion on methods of assessment found in this paper. These methods of assessment can be either formative or summative; formative assessments provide feedback in the early stages of student's design knowledge experience which helps to ensure the development of their capabilities, while summative assessments provide a measure of the program impact on student achievement, necessary for evaluating the full scope of an engineering degree program[5]. The initial generation of the instrument was for the purposes of summative assessment since it was only presented to graduating students. This approach allows for the observation of the engineering disciplines as a whole as well as through a single capstone course.

Other approaches to tools used in academic settings have presented the class with rubrics and charts that require certain elements to be ranked on a discrete scale by the students[5,6]. These elements included terms that defined engineering design as well as a way of showing the student's personal growth through the course. By having the students complete a self assessment, the instructors were able to gauge the student opinions of what had been learned in their course.

When looking at the industrial uses for skills and concept inventories, it is obvious that they do not serve the same purpose as those distributed in an academic environment. Most employers are looking for specific skills and talents that are applicable to the job being applied to. A current method that exists can be seen in Figure 5. This inventory simply requires the applicant to note their experience in a certain area. This contributed to instrument design in helping to establish the question that looks at the student's experience with design courses in past years.

Skill 2. Civil engineering

Code	Specialization	Examples, description
1.2.1.	Finishing and repair work	Heating, sanitary, carpentry, metal work, etc.
1.2.2.	Industrial buildings	
1.2.3.	Metallic structures	
1.2.4.	Road and drainage works	
1.2.5.	Underground structures	
1.2.99.	Other	Please specify in details

Figure 5: Existing Method for Industrial Skills and Talents Inventories[7]

Each of the above examples reveals that a method does not yet exist for assessing student conceptions, especially not in the area of engineering design, which further encouraged the design of the instrument.

Initial Instrument Composition

The initial instrument composition resulted in a combination of each of the aforementioned sources. The question composition was established to look at four important areas: the student's exposure to engineering design throughout their undergraduate career, the student's perception of engineering design in verbal and visual form, the qualities of a good engineering designer, and the important topics to be covered in an engineering design course.

The purpose of the sources identified prior was to generate the overall list of qualities and topics shown in the tables within the instrument. The first list was created using the interview results. This list was then expanded upon using curricular requirements. The combination of the interview results and curricular requirements were identified as the most important of the list since they would reveal that the students were meeting the course objectives and satisfying the requirements for graduation. The literature review and past methods of assessment were used to determine which items should further be included by looking for redundancy among these sources.

Instrument Revision

Once the first version of the instrument was completed, it was important to gain external perspectives to justify the clarity and cohesiveness prior to presenting it to the test subjects. This was done through three different mediums. Primarily, the Faculty supervisors of this project reviewed it for initial feedback prior to distribution for the next round of analysis. The following set of analyses took place in parallel; the instrument was sent to the professors involved in the interview process, and it was presented to a group of fourth year undergraduate engineering students.

It was important for the professors to agree with what was being presented through the instrument as it was a reflection, in part, of their personal beliefs on engineering design. Overall, the professors were in agreement with the composition of the instrument, but a slight change was made to include troubleshooting as a design skill in addition to debugging; the reason being that troubleshooting is a way of preventing the need for debugging. Since some professors still believe there is a need for debugging, this remained as well.

The student sample represented a diverse group, with varying academic standings and disciplinary backgrounds. This sample was selected from a large group of fourth year students, based on their willingness to participate. The students were an important part of instrument revision since this helped to determine concepts that may have been communicated poorly and to suggest modifications to these questions. Following this revision, the instrument was edited and became what is presented in this paper.

Conclusion

The development of this instrument has allowed for a first attempt to look more closely at a missing element of engineering design education; the assessment of student perceptions at the culmination of a course or program. The next step will be to deploy this instrument within a class of engineering students.

The instrument development employed a process that unified engineering design definitions and processes by looking at input from professors, curricular requirements, literature and past tools, but it is hoped that the tool can be used to measure the diverse viewpoints of students about engineering design across all engineering disciplines, and also measure the similarities and differences between student and professor perspective. Following further analysis and verification, the instrument will serve as a valuable tool to help understand and unify multidisciplinary teams in the future.

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Appendix A – The Instrument

Appendix A.1 – Initial Instrument Composition

Note: This version of the instrument also includes the justification for the inclusion of each question and the information that it should provide to the assessor. This is captured under the heading "Reason".

Instrument v1.1

1. What is your engineering discipline or program?
Reason: Disciplinary perspective data.
2. How many engineering design courses have you taken? Please list them if you would like to.
Reason: What is the student's opinion of what constitutes an engineering design course?
    a. In what years did you take these courses?
    Reason: Looking at placement within the curriculum and whether or not there is extended exposure.
    b. What was your most significant learning experience within any of your design courses? (It is not necessary to list the course name if you do not want to.)
    Reason: What has the largest impact from the student's perspective?
3. Within your current capstone design course, identify three (3) requirements/constraints and explain how they had a direct influence on the final design of a system, process, or component.
Reason: Looks for recognition of the most important/influential design factors.
4. Define engineering design.
Reason: Will highlight important identifiers and keywords that can be used for further analysis in different forms.
5. Illustrate your definition of engineering design, identifying any key elements.
Reason: Point of comparison to professor, between disciplines, to general processes identified within the literature.

6. In the table below, there are several skills and qualities listed that are considered to be attributes of an engineering designer as defined by several sources. In the column labeled "Agree", use a checkmark to indicate whether or not you believe it is in fact an attribute; in the column labeled "Possess", use a checkmark to indicate whether or not you believe that you exhibit this attribute and have experienced explicit development in this area through your design courses; and in the column labeled "Rank", using the numbers 1 through 5, indicate what you believe to be the most important attributes of an engineering designer, with 1 being the most important.

Skill/Quality	**Agree**	**Possess**	**Rank**
Ability to break down a large project or process			
Ability to bring theory into practice			
Ability to debug a system			
Ability to identify the pros and cons of a particular solution			
Ability to iteratively approach a problem			
Analytical/critical thinking			

Confidence			
Costing experience			
Creativity			
Decision-making			
Ethical			
Initiative			
Leadership			
Open-minded			
Organization			
Problem solving			
Professionalism			
Recognition of the need for, and an ability to engage in life-long learning			
Researching			
Self-growth			
Team player			
Willing to follow a process			

Reason: to identify, compare/contrast the skills of an engineering designer as recognized by the students to those opinions of the literature and professors.

7. In the table below, there are several topics that have been recognized as fundamental elements of an engineering design curriculum. In the column labeled “Agree”, use a checkmark to indicate whether or not you believe this is a fundamental topic pertaining to engineering design; in the column labeled “Used”, use a checkmark to indicate whether or not you have had exposure to this topic and an additional checkmark if you discussed it in your current capstone design course; and in the column labeled “Rank”, using the numbers 1 through 5, indicate what you believe to be the most important topics pertaining to engineering design are, with 1 being the most important.

Topic/Focus	**Agree**	**Used**	**Rank**
Analysis of data and engineering projects			
Argumentation and support			
Assessment of needs			
Case studies			
Communication (oral, visual, written)			
Computer aided design			
Concept generation			
Contemporary issues within a society or environment			
Creativity training			
Decision-making processes			
Determination and classification of constraints			
Economic analysis			

Experiment design			
Gathering and interpreting information			
Generating and analyzing alternative designs			
Impact of designs (ethically and socially)			
Leadership training			
Manufacturing processes			
Open-ended problem solving			
Optimization of processes and designs			
Understanding of the industry			
Problem definition and scoping			
Product design and development			
Product marketing			
Product testing			
Professional and ethical responsibility			
Project documentation			
Project management and planning			
Rapid prototyping			
Reflection			
Resource management			
Reverse engineering			
Safety, standards, and regulations			
Sustainability			
System modeling			
Team work and group dynamics			
The role of technology in society			

Reason: to identify, compare/contrast the key topics of engineering design as recognized by the students to those opinions of the literature and professors.

- Do you have any final comments or thoughts that you would like to include?
- If you would be interested in participating in further research of this nature or asking any questions regarding my current research, please include your e-mail address.
- Thank you for your time!

Appendix A.2 – Final Instrument Composition

NOTE: All submissions are anonymous, and no responses will be shared with your professor. This has absolutely NO influence on your performance in the course.

Take **capstone design course** to mean: "a significant design experience which is based on the knowledge and skills acquired in earlier course work and which preferably gives students an exposure to the concepts of team work and project management." (CEAB, 2006)

1. What is your engineering discipline or program? ___________________________________

2. List all of the engineering design courses you have taken and in what year they were taken.

Design Course	**Year (1, 2, 3, or 4)**

3. Do you engage in a formal process of engineering design? Yes No

4. Define engineering design.

5. Give a graphical representation, in a form similar to that of a flow chart, to summarize your conception of engineering design.

6. The table below lists a number of skills and qualities listed that are considered to be attributes of a good engineering designer.

- In the column labeled “Agree”, use a checkmark to indicate whether you agree it is in fact a quality necessary for a good engineering designer to possess;
- In the column labeled “Taught”, use a checkmark to indicate whether you have experienced explicit development in this area through your design courses;
- In the column labeled “Top 5”, using the numbers 1 through 5, indicate what you believe to be the top 5 (only) important attributes of an engineering designer, with 1 being the most important.

Skill/Quality	**Agree**	**Taught**	**Top 5**
Ability to break down a large project or process			
Ability to bring theory into practice			
Ability to debug a system			
Ability to identify the pros and cons of a particular solution			
Ability to iteratively approach and solve a problem			
Ability to make credible decisions			
Analytical/critical thinking			
Confidence			
Costing knowledge and experience			
Creativity			
Ethical			
Initiative			
Leadership			
Life-long learner			
Open-minded			
Organization			
Problem solving			
Professionalism			
Researching			
Self-growth			
Team player			
Willing to follow a process			

7. The table below lists a number of topics that have been recognized as fundamental elements of an engineering design curriculum.
   - In the column labeled “Agree”, use a checkmark to indicate whether you agree this is a fundamental topic pertaining to engineering design;

- In the column labeled “Taught”, use a checkmark to indicate whether you have had exposure to this topic through your design courses and an *additional* checkmark if you discussed it in your current capstone design course;
- In the column labeled “Top 5”, using the numbers 1 through 5, indicate what you believe to be the top 5 (only) topics pertaining to engineering design are, with 1 being the most important.

Topic/Focus	**Agree**	**Taught**	**Top 5**
Analysis of data and engineering projects			
Argument development and support			
Assessment of needs			
Case studies			
Communication (oral, visual, written)			
Computer aided design			
Concept generation			
Contemporary issues within a society or environment			
Creativity			
Decision-making processes			
Determination and classification of constraints			
Economic analysis			
Experiment design			
Gathering and interpreting information			
Generating and analyzing alternative designs			
Impact of designs (ethically and socially)			
Leadership			
Manufacturing processes			
Open-ended problem solving			
Optimization of processes and designs			
Understanding of the industry			
Problem definition and scoping			
Product design and development			
Product marketing			
Product testing			
Professional and ethical responsibility			
Project documentation			
Project management and planning			
Rapid prototyping			
Topic/Focus	**Agree**	**Taught**	**Top 5**
Reflection			
Resource management			
Reverse engineering			

Safety, standards, and regulations			
Sustainability			
System modeling			
Team work and group dynamics			
The role of technology in society			
Troubleshooting			

For the table above:

- In the column labeled “Agree”, use a checkmark to indicate whether you agree this is a fundamental topic pertaining to engineering design;
- In the column labeled “Taught”, use a checkmark to indicate whether you have had exposure to this topic through your design courses and an *additional* checkmark if you discussed it in your current capstone design course;
- In the column labeled “Top 5”, using the numbers 1 through 5, indicate what you believe to be the top 5 (only) topics pertaining to engineering design are, with 1 being the most important.

Do you have any final comments or thoughts on design and design education that you would like to include?

If you have any questions regarding my current research, please include your e-mail address. (Your responses will still remain anonymous.)

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Thank you for your time!