AC 2009-680: EXAMINING STUDENT USE OF EVIDENCE TO SUPPORT DESIGN DECISIONS

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Examining student use of evidence to support design decisions

Abstract

Our efforts have focused on investigating the type of knowledge students use when making decisions in the process of developing design solutions. In particular, we document the type of evidence students provide when presenting various design alternatives, or when they suggest a particular design approach or solution. One major aim of our work is to investigate how flexible students are in applying disciplinary knowledge in the process of design. Specifically, our research seeks to explore the role that computational and analytical abilities play in innovation in the context of engineering design education. We apply the learning framework of adaptive expertise to focus our work and guide the research. Using the adaptive expertise framework, with a specific focus on computational/analytical knowledge, we document the type of evidence students do (or do not) use when selecting possible design alternatives, appropriate models or methods of analysis, and when interpreting the results to justify their decisions.

We analyzed student design project reports from different academic years, and from different engineering disciplines. Specifically, our data consists of first-year and capstone design experiences. This comprehensive data set enables us to compare the nature of students' decision making and the type of analytical knowledge used across the undergraduate time span. Results from this research shed light on how students use disciplinary knowledge in the process of design, what students consider to be important technical information for design, and how students make design decisions, sometimes with and without appropriate evidence to support their decisions.

Introduction

The National Academy of Engineering's report on the attributes of the Engineer of 2020[1] say that the engineer of the future should have strong analytical skills, practical ingenuity, creativity, good communication, business, management, and leadership skills, a strong sense of professionalism, and be a lifelong learner. The future engineer should be innovative as well as knowledgeable. The attribute of "practical ingenuity" describes future engineers as technically fluent as well as innovative. The education of the future engineer must be able to prepare engineers to approach situations flexibly and with technical expertise.

To further understand how to prepare students to have "practical ingenuity," we are investigating how flexible students are in applying disciplinary knowledge in the process of design. Specifically, we seek to explore the role that computational and analytical abilities play in innovation in the context of engineering design education. We are investigating students' use of knowledge when making decisions in the process of developing design solutions.

Background Literature

Our study is exploring the use of student knowledge during decision making in the engineering design process. Ulrich and Eppinger[2] present a framework for the design process. A six phase model is used to present the complex design process as a series of actions: Planning, Concept

Development, System-level Design, Detail Design, Testing and Refinement, and Production Ramp-up. Each action is accompanied by design tasks, (i.e., identifying customer needs, determining product specifications, generating concept alternatives). Dym and Little[3] provide a similar framework for the design process. They offer a five-stage prescriptive model of the design process detailing the major activities and the design tasks associated with the activities. The model consists of Problem Definition, Conceptual Design, Preliminary Design, Detailed Design, and Design Communication stages. In both of these models, the major decision making occurs during Conceptual, Preliminary, and Detailed Design stages in the form of establishing design specifications, generating and evaluating design alternatives, and optimizing chosen design. The designers document their rationale behind design decisions throughout the design process, and organize these justifications into the written report in the Design Communication stage.

We are particularly interested in analyzing the types of knowledge students use to create evidence to support their design decisions. One specific type of evidence in which we are interested is computational/analytical knowledge. We seek to investigate student flexibility in applying disciplinary knowledge in design decisions. This study uses the learning framework of adaptive expertise, where development occurs along two axes: innovation and efficiency[4]. We specifically focus on computational/analytical knowledge in adaptive expertise (CADEX), and how students flexibly used computational knowledge in design decisions. In this study, we document the type of evidence students do (or do not) use when selecting possible design alternatives, appropriate models or methods of analysis, and when interpreting the results to justify their decisions.

Research Method

This project is investigating the role that computational and analytical abilities play in the process of innovation in the context of the adaptive expertise framework[5]. The current work is guided by the following research questions:

- What is the nature of computational knowledge required in the process of design and innovation?
- What is the nature of the evidence used in the design decision making process?

In order to investigate these questions we used a qualitative approach of analyzing student design reports to document and categorize students' design decisions. Specifically, we coded students' project reports for instances of when a design decision had been made. We used Beheshti's description as a framework to help identify decision decisions, that is, a design decision is made from available design alternatives that have been evaluated against a set (or multiple sets) of design criteria[6]. The results of these evaluations against design criteria are considered evidence that support or refute the choice of design alternatives. For example, the passage below demonstrates a team's design decision to pursue a certain design alternative.

We decided to forgo the Y-release mechanism in Design A for the current quick release mechanism on Design B. The Y-release would have consisted of a complex system of springs, cables, and pulleys. This would have increased the number of parts and the complexity of assembly which goes directly against our goal to decrease the number of parts in the product. The Edge-n-*Roll's quick release mechanism is simple and does not require many parts*[7].

The design criteria established by this team was to decrease complexity and the number of parts. The team evaluated two design alternatives, counting the number of parts and determining complexity of assembly. The team then made the design decision to pursue Design B.

For each team, we recorded instances of design decisions, along with a record of whether evidence was provided. For decisions supported by evidence, we categorized the evidence into two categories: (1) Evidence from Own Work (such as a calculation, building a model, or performing an experiment) or (2) Evidence from Other Sources (such as advice or recommendations from an expert in the field or from literature or patent searches). Of the team's own evidence, we documented whether the evidence was of a CADEX nature (such as performing a calculation or series of calculations, plotting experimental data and finding line of best fit, or modeling). Of the cases where students did not show evidence for a design decision, we noted the lack of evidence.

The reports analyzed in this study come from three different courses. The first of which is a senior capstone design course in Biomedical Engineering (BME). Students in this course are evaluated on initial and midterm presentations and reports on progress in addition to the final report and presentation. The final report must showcase a single product concept and include a summary of the market, technical feasibility, and analysis of the challenges to development, manufacture, and delivery of product. Projects in this course ranged from the development of devices such as a tool to crush medications for use in feeding tubes or a hernia simulator for medical training, to the creation of tools such as a computerized, user-directed posture correcting system. During this study, the BME course contained nine groups of three to four students each.

The second course is a senior capstone design course in Mechanical Engineering (ME). The final report requirement for the senior capstone design courses is to showcase a single design concept. Projects in this course included the development of an adjustable height desk, a trim painting tool, an electric skateboard, and a wheelchair with single hand control. This course included four teams of four to five students each at the time of the study.

The third course is offered in Engineering Design and Communication (EDC), a required course for all engineering first and second year students. The final report for the EDC course is a final "proposal" where the design is "explained with sufficient detail, evidence, and reasoning to persuade the client it solves the problem in a way that fulfills the major stakeholder needs." The projects in this course ranged from the formation of a tool for testing electronic components at high pressures, to creation of devices such as a volleyball delivery system for athletic training, to development of an awareness program for young students encountering peers with autism. Ten groups of three to four students were analyzed from the EDC course during this study.

For all three courses, students are interacting with real clients to design solutions that fulfill a real need. Only the final reports for these courses were analyzed in this study. The following results consist of one academic quarter of BME, ME, and EDC design courses, providing us with a snapshot of the approaches to design solutions used by seniors and freshmen.

Results

The goal of this project was to determine the nature of the knowledge students use to support design decisions, particularly the flexible use of computational/analytical knowledge. We documented the nature of the evidence students reported in their project reports and also noted when decisions were made without any supporting evidence. The following section compares the type and amount of evidence used in design decisions from capstone and freshman courses and across disciplines.

In the BME and ME capstone design courses, students averaged more decisions recorded per report than students in the freshman EDC course. Figure 1 shows the average number of decisions made per design report for the BME, ME, and EDC courses. The much larger number of decisions per report made by the ME students may be attributed to the mechanical nature of their projects and the attention to mechanical details. For example, many of the ME reports included decisions over bolts, pins, fasteners, and mountings. On the other hand, the students in the BME course paid close attention to details pertinent to their training, such as the selection of material that are compatible with the human body, and whether a device can simulate human behavior, but the reports contained fewer details on the nuts and bolts and complete device assembly.

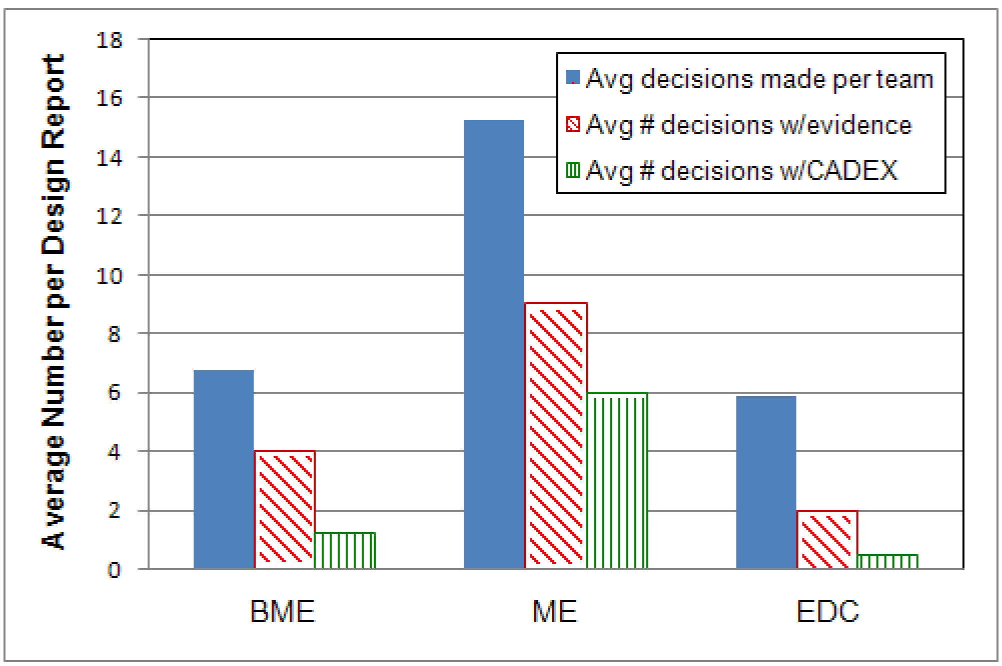


Figure 1: Average number of decisions made per team report for BME, ME, and EDC courses. Average number of decisions supported with evidence, including CADEX specific evidence, for each course.

Figure 1 and Figure 2 illustrate the improvement of the capstone BME and ME courses in providing evidence to support design decisions compared to the freshman EDC course. The students in the capstone courses provided evidence for over 55% of the recorded decisions within the reports. The type of evidence provided is broken down in Figure 2 to show the percent of evidence created by the students and the percent of evidence sought by the students from outside sources. Figure 1 also shows the amount of CADEX evidence provided in the support of design decisions.

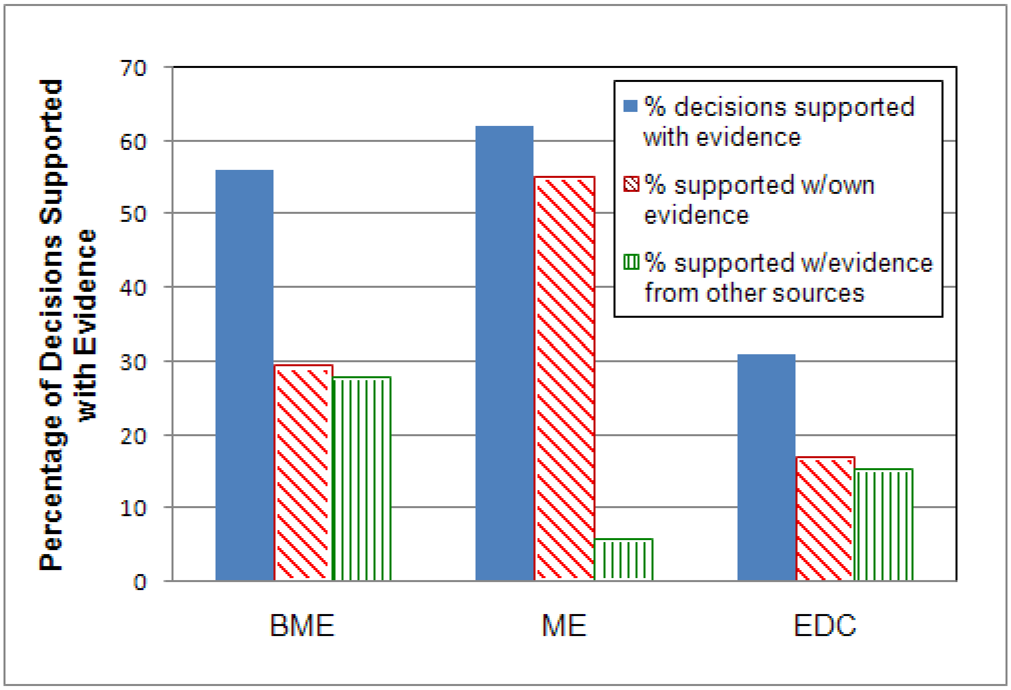
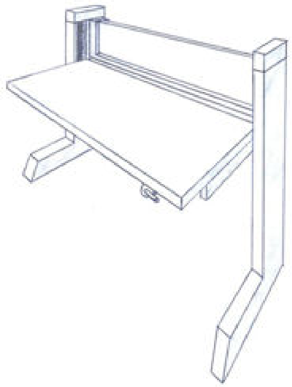
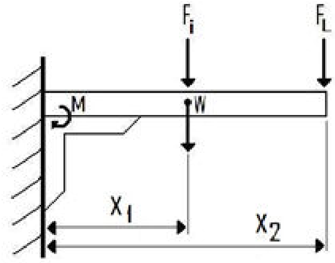


Figure 2: Percentage of report decisions supported with evidence, broken down by whether evidence is created by student team, or sought by team from other sources.

In Figure 2 we see that 55% of the decisions made by ME students were supported by their own evidence, and only 6% of the decisions were supported by evidence from other sources. Additionally, Figure 1 shows that 41% of all decisions were supported by CADEX evidence. For the ME reports, most of their own evidence was in the form of calculations. Figure 3 below provides an example of a calculation from an ME report. BME students supported 30% of their decisions with evidence of their own creation, much of this in the hands-on form of physical observations or experimental testing. In the BME reports, 31% of the students' own evidence was CADEX evidence, provided as plots and calculations stemming from the students' observations and experiments. Figure 4 below illustrates experimental data collection from a BME report.



Prototype adjustable height desk



Moment about "C-leg" support
F_L – max load (150)
W – weight of desktop
F_i – weight of items on desk

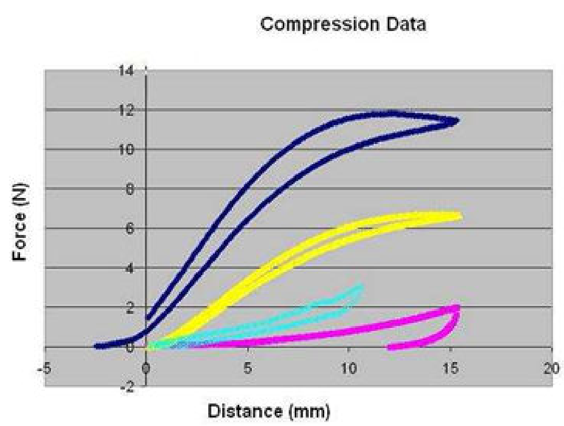
$$M = W * X_1 + F_i * X_1 + F_i * X_2 = 205 * 0.25 + 133 * 0.25 + 667 * 0.51 = 382Nm$$

Bending stress for a rectangular beam: $\sigma = \frac{6M}{bh^2}$

b – length of base (¾ inch), h – height of the rectangle (5 inch)
Bending stress = 7 MPa

Our prototype supports are made of plywood, which has a yield strength of 31 MPa, resulting in a safety factor of 4.4

Figure 3: Calculation in the design of the support for an adjustable height desk from an ME report[8].



Purple – porcine intestine
Dark blue – solid hemisphere of HS II silicone
Yellow – hollowed hemisphere
Light blue – model material

One of the most important pieces of quantitative information pertinent to ensuring the accuracy of our product is finding out how much force is required to compress the hernia a particular distance. If this force were too high, it could be concluded that the artificial hernia was too stiff and that the opposite would demonstrate a hernia that was too yielding. Compression tests were performed comparing different models to a section of pig intestine obtained from a slaughterhouse. A metallic sphere with a diameter of 5/8'', roughly the diameter of the human index finger, was attached to the end of the machine arm, and a computer recorded the normal force felt by this arm as it was gradually lowered into the material.

Figure 4: Collection of experimental compression data for the calculation of force/displacement for various materials considered for a hernia simulator from a BME report[9].

In comparison with the capstone courses, the freshman EDC course only supported an average of 31% of decisions with any type of evidence. Seventeen percent of all recorded design decisions in EDC reports was supported with students' own evidence, with 8% of all design decisions supported by CADEX evidence. With less disciplinary knowledge at hand in comparison with the seniors in capstone design, the freshmen in EDC provided their own evidence in the form of tables comparing various design alternatives with a "pros and cons" or alternative type of ranking system. The types of CADEX provided by the EDC students is mainly in the form of physics calculations and force diagrams, indicating that the students are transferring knowledge from other courses, but that the amount of knowledge is limited by fewer past courses.

Figure 2 also shows that students relied on other sources to support their design decisions. ME reports averaged 6% of all decisions supported by evidence from other sources in the form of research into existing products and patent searches. BME reports average 28% of all decisions supported by evidence from other sources in the form of literature sources, expert advice, user testing, and client feedback. And finally, EDC reports averaged 15% of all decisions supported by evidence from other sources in the form of user testing, expert advice, and literature sources.

Summary and Future Work

Figure 1 indicates that design teams in the capstone courses offer a higher number of decisions per report, with the ME capstone teams providing more than double the number of decisions than the teams in the freshman course. One reason for the much higher number of decisions in the ME reports may be due to the mechanical nature of the designs and meticulous design decisions toward the completion of the final product. Furthermore, teams in capstone courses support their decisions with evidence more often than teams in the freshman course. Figure 1 also shows that design teams in capstone courses supported over 55% of decisions with evidence, while the freshman teams supported only an average of 31% of decisions with evidence.

Figure 2 displays the differences in the types of evidence provided by the capstone and freshman design teams. As mentioned before, the capstone design teams surpassed the freshman teams in providing evidence to support design decisions. Of the two capstone courses, the ME teams used their own evidence nine times more often than evidence from other sources. The BME teams provided evidence of their own creation as often as they used evidence from other sources. The BME teams were more likely than ME teams to seek out an expert opinion or consult current literature. The freshman teams also used a fairly equal amount of their own evidence and evidence from other sources.

When using their own evidence, the ME teams were more likely to use CADEX evidence. Sixty-eight percent of the evidence provided by ME teams was CADEX evidence, whereas BME and EDC teams provided only 31% and 26% CADEX evidence, respectively. With the CADEX evidence, it could be seen that a higher level of expertise and innovation was apparent in the capstone teams. The capstone teams were more likely to use more sophisticated calculations, indicating that there is recognition of the role of higher level analysis in design and innovation. The freshman teams also demonstrated recognition of the role of CADEX evidence, but the complexity of the knowledge was limited by fewer past courses.

One consideration for future studies may be to assess how far into the design process the freshman teams progress. Inability to proceed past the Conceptual or Preliminary Design stages of the design process could hamper the number of decisions these teams could make.

To further study the knowledge students use in decision making, we are currently investigating the students' decision making during all the stages of the design process, from Problem Definition to Design Communication. In particular, we are taking a more ethnographic approach to gain a better understanding of the factors that influence the teams' decisions in real time. Specifically, we are observing and videotaping teams as they engage in critical decision making steps in the design process, e.g. design reviews, client meetings, and final presentations. From these observations we will obtain real-time data about how teams make decisions and how they reason about evidence. We hope that these observations will illuminate parts of the decision-making process that do not appear in a final design report. Finally, we will also analyze students' design documentation they produce throughout the project including progress reports, midterm presentations, as well as final reports.

Acknowledgements

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