ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

New Orleans JAZZED about Engineering Education

Paper ID #15679

Designettes in Capstone: Characterizing the Impact of Early Design Experiences on Students' Capstone Education

Lt. Col. Cory A. Cooper, United States Air Force

Lieutenant Colonel Cory Cooper is currently the Director of the Systems Engineering Program and Assistant Professor of Systems Engineering at the US Air Force Academy (USAFA) in Colorado Springs, Colorado. He holds a PhD an MSc in Systems Engineering from the Technical University of Delft and the Air Force Institute of Technology respectively. He has held various developmental engineering and program management positions in the US Air Force, to include Deputy Director for Airworthiness in the F-35 Lightning II Program Office, deployed Joint Combat Damage Assessor for US/Coalition/Contractor/Afghan aircraft in Afghanistan, Chief of Operations for the Systems Engineering Program at USAFA, Mechanical Systems Engineer in the C/KC-135 Program Office, and deployed Aircraft Battle Damage Repair Engineer for B-1B aircraft.

Lt. Col. Michael Lawrence Anderson, United States Air Force

Lt Col Mike Anderson is an Assistant Professor of Engineering Mechanics at the US Air Force Academy where he has taught since 2004. He received his BS and MS in Mechanical Engineering at the US Air Force Academy, and University of Utah, respectively, and his PhD in Aeronautical Engineering at the Air Force Institute of Technology in 2011. He has worked as an F-16 flight control actuation systems engineer, researched design and control of quadruped robots, led research and development of advanced Air Force munitions, and led research in GPS-denied navigation for multi-agent autonomous systems for the Air Force Research Laboratory (AFRL). Lt Col Anderson has been researching innovative design methodologies and autonomous systems for 12 years, authoring several papers relevant to the field, including award-winning research into the design and control of flapping wing Micro Air Vehicles. Lt Col Anderson is a registered Professional Engineer and an Associate Fellow of the American Institute for Aeronautics and Astronautics. In 2013 he was named the Air Force Research Laboratory's Field Grade Officer of the Year, and in 2014, he was awarded AFRL's Leadership Award for outstanding leadership in R&D out of over 3,000 of his peers.

Dr. Daniel D. Jensen, U.S. Air Force Academy

Dr. Dan Jensen is a Professor of Engineering Mechanics at the U.S. Air Force Academy where he has been since 1997. He received his B.S. (Mechanical Engineering), M.S. (Applied Mechanics) and Ph.D. (Aerospace Engineering Science) from the University of Colorado at Boulder. He has worked for Texas Instruments, Lockheed Martin, NASA, University of the Pacific, Lawrence Berkeley National Lab and MSC Software Corp. His research includes design of Micro Air Vehicles, development of innovative design methodologies and enhancement of engineering education. Dr Jensen has authored over 100 refereed papers and has been awarded over $4 million of research grants.

Dr. Joseph M. Fulton, U.S. Air Force Academy

Dr. Joseph Fulton is currently an Assistant Professor of Systems Engineering and Director of Assessment and Accreditation for the SE Program at USAFA. He holds a PhD and MS in Astronautical Engineering from the University of Colorado and the Air Force Institute of Technology respectively. He has held various developmental engineering and program management positions in the US Air Force, to include Deputy Group Commander of Wideband Satellite Communications, Chief Engineer of Wideband Global SATCOM (WGS) satellite constellation and Program Manager of the Defense Satellite Communications System (DSCS) at the Space and Missiles Systems Center in Los Angeles, California. In addition, he served as the Deputy Head of the Department of Astronautics at USAFA and as a Flight Commander and Instructor for Intercontinental Ballistic Missile (ICBM) operations at Malmstrom Air Force Base, Montana.

Dr. Kristin L. Wood, Singapore University of Technology and Design

Dr. Kristin L. Wood is currently a Professor and Head of Pillar, Engineering and Product Development (EPD), and Co-Director of the SUTD-MIT International Design Center (IDC) at the Singapore University of Technology and Design (SUTD). Dr. Wood completed his M.S. and Ph.D. degrees in the Division of Engineering and Applied Science at the California Institute of Technology, where he was an AT&T Bell Laboratories Ph.D. Scholar. Dr. Wood joined the faculty at the University of Texas in September 1989 and established a computational and experimental laboratory for research in engineering design and manufacturing, in addition to a teaching laboratory for prototyping, reverse engineering measurements, and testing. During his academic career, Dr. Wood was a Distinguished Visiting Professor at the United States Air Force Academy. Through 2011, Dr. Wood was a Professor of Mechanical Engineering, Design & Manufacturing Division at The University of Texas at Austin. He was a National Science Foundation Young Investigator, the "Cullen Trust for Higher Education Endowed Professor in Engineering," "University Distinguished Teaching Professor," and the Director of the Manufacturing and Design Laboratory (MaDLab) and MORPH Laboratory. Dr. Wood has published more than 350 refereed articles and books; has received more than 40 national and international awards in design, research, and education; and is currently a Fellow of the American Society of Mechanical Engineers.

Designettes in Capstone: Characterizing the Impact of Early Design Experiences in Capstone Education with Emphasis on Designette Project Choice

Cory A. Cooper,[a] Michael L. Anderson,[a] Daniel D. Jensen,[a] Joseph M. Fulton,[a] Kristin L. Wood[b]

[a]United States Air Force Academy, Colorado, USA
[b]Singapore University of Technology and Design, Singapore

Abstract

Full engineering design experiences often require months to accomplish. In an effort to incorporate design, design thinking, and design innovation into curriculum without consuming extensive time, the use of shortened design experiences, referred to as "designettes," has been undertaken. A designette can provide a partial or concentrated design experience by either removing certain parts of a full design process, or by focusing on certain steps, or both. A designette allows students various experiences with the design process that can provide a "learning scaffold" for their implementation of the full suite of design methods over the course of a longer project. Designettes likewise provide a mechanism and construct for learning multi-disciplinary technical content and skill sets. In the current educational research, the project focus of a designette was selected from one of two options: either a small, related portion of a larger project, or a totally unrelated project with respect to a larger project. The advantage of a designette being a small part of a larger project is that the time spent on the designette is directly related to the project goals of that larger project. The advantage of having an unrelated designette is that the students feel freedom to take risks and focus on creativity and innovation because they do not experience the stress related to satisfying the sponsor that comes with the larger project. Faculty and student feedback was primarily used to characterize and compare the designette's effectiveness. The current research shows that there are distinct advantages and disadvantages to having the designette project either related, or unrelated to a longer term, sponsored project, such as in a capstone experience. Those who implement designettes can use the detailed data provided in this research to determine which approach best matches their capstone program's distinctive attributes and goals.

1. Introduction

Capstone courses are a part of all Accreditation Board for Engineering and Technology (ABET) accredited engineering programs. These courses create wonderful opportunities for engineering students to apply the tools they have learned throughout their academic engineering training. Often a capstone experience is the first time that students are applying the design process to a real industry, government, or societal problem with sponsors. This context can result in a lack of understanding of the larger, more comprehensive system design lifecycle when it comes to implementation of the specific steps in the design process. Constructivist learning theory[1] indicates that it may be more efficient and effective if students had some exposure to, experience with, or multiple iteration with the design process before they implement that process in the context of a real-world capstone project.

Capstone design courses provide a culminating engineering experience through design of a real-world product or system.[2, 3] The design and creation of an engineered system in collaboration with a multidisciplinary team addresses key tenets of the ABET recommended student outcomes.[4] While the ABET "General Criterion 3: Student Outcomes A-K" are meant to be satisfied throughout an entire curriculum, the course outcomes of most engineering capstones seek to meet most of these outcomes in an integrated fashion during capstone design courses. The following outcomes are used to frame and assess the capstone engineering course in the department of this research.

1. Given a statement of customer need, students design a system to satisfy that need based on commercial product development best practices.
2. Students will demonstrate the ability to effectively communicate their design.
3. Students will demonstrate the ability to fabricate a functioning prototype of their design.
4. Students will demonstrate the ability to be effective interdisciplinary team members and leaders.
5. Student designs will comply with a realistic level of engineering codes and standards and shall include considerations such as environment, economics, manufacturability, sustainability, health and safety.

There are a variety of options when it comes to teaching both design process and the actual capstone course(s).[5] Some schools have a separate course in design methods.[6, 7, 8, 9] This would then be followed by either a one or two semester capstone course. Other schools integrate the instruction in design methods or processes into the one or two semester capstone experience.[10] As previously mentioned, this may be the first time that students have been exposed to a formal, complete design process.

In the case where the capstone project is the students' first implementation of the formal design process, it is common for the students to have difficulty understanding the motivation behind the design process. Techniques like "Customer Needs Analysis," "Functional Decomposition" and "Quality Function Deployment" are often met with resistance by students who want to proceed directly to a build/test phase. Even when students are encouraged to follow a formal design process, they often fail to see the relationship between the different parts of the process as well as how the process ultimately saves them time and increases their likelihood of development of a successful product or system. Even in industrial design environments, engineers sometimes fail to see the utility to following a formal design process.[11]

In addition to determining the various options for delivery of the design content and the implementation of the capstone project, research shows that it is beneficial to balance inductive learning and deduction instruction methods.[12] Traditional instructional methods can lean towards presenting the general case for a concept (deductive method) and then provide examples (inductive) that support that generalization (though, good instructors will balance this approach with inductive methods). Students, on the other hand, tend to form a framework of understanding based on specific experiences or examples and then accept a general concept – inductive learning. As a largely experiential course, the capstone can support the inductive learning style well. The necessary deductive-style teaching of accepted engineering design steps should be balanced with the inductive learning of the students. The challenge lies in allowing the experiences of the students' inductive learning to occur with enough time to reflect and build their cognitive framework.

Finally, a look at the Kolb cycle (Figure 1) and its application to the design curriculum and capstone program could be informative. The Kolb model is characterized by a cycle that begins with concrete experience, proceeds with reflective observation and conceptualization, and ends, before restarting, with active experimentation. Educational environments that incorporate all four (4) steps in the cycles have been shown to more fully span the spectrum of student learning styles.[12, 13, 14, 15] Design projects inherently incorporate Concrete Experience, Abstract Hypothesis & Conceptualization and Active Experimentation. However, if the capstone experience is the first time that formal design process is introduced to the students, the opportunity for Reflective Observation becomes more difficult as the students are literally thrown into a high intensity design process where failure to develop a good product or system could lead to failure to obtain their engineering degree.

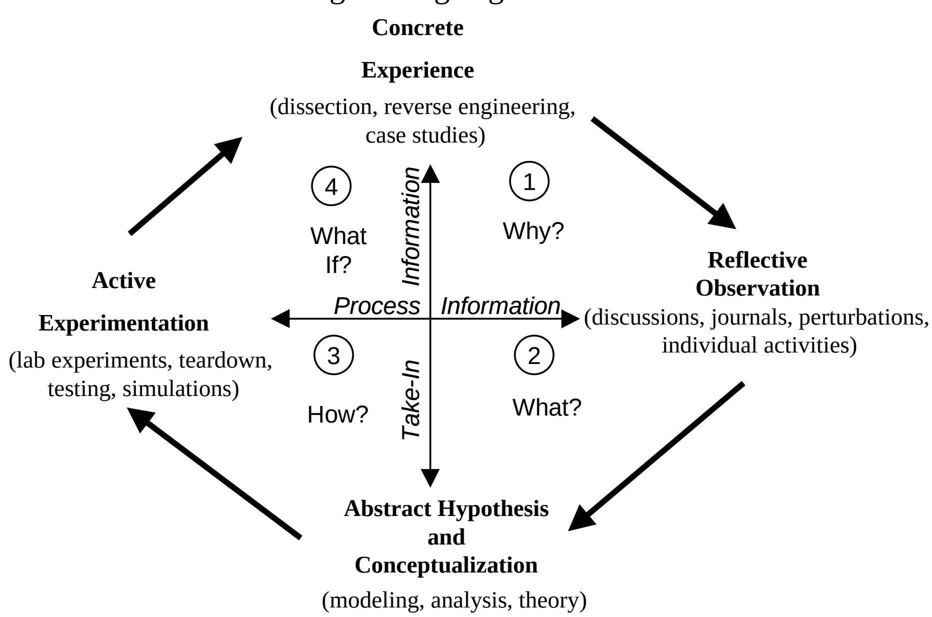

Figure 1: Kolb's Cycle of Learning

One method to alleviate the issues associated with having the full capstone project be the first time students are introduced to the design process is to begin the capstone course with what is called a designette. Designettes can provide an initial experience in the design process with a minimal time commitment (often two (2) hours of class time and four (4) hours of time outside of class). This initial design experience can provide a context for students to become familiar with the design process in a less risk adverse situation than the actual capstone project affords. The familiarity with the design process which is gained from the designette can also increase confidence in the utility of the design process tools.

Content for the designette can either come from the actual capstone project, or could be unrelated to the actual project. Advantages and disadvantages of these two options for designette content is the focus on much of the present research.

2. Related research

Improvements in capstone design content and delivery have been the focus of significant pedagogical research for years. Of particular relevance to this paper's research is the concept of a "designette."[8, 16, 17, 18, 19, 20] Originally coined at the Singapore University of Technology and Design (SUTD), designettes[a] are described by the originators as "glimpses, snapshots, small-scale, short turnaround and well-scoped design problems that provide a significant design experience."[16] The use of designettes was "found to increase students' self-perceptions of their ability to solve multidisciplinary problems."[17, 18] Within this design instruction paradigm of designettes, the methods proposed in this paper would most easily align with the 2D level of designettes—projects that integrate multiple course topics. In addition to the concept and framework of designettes, its originators have also provided an extensive overview of their benefits and a review of various universities' approach to capstones. Following this review of other programs, ten "designette characteristics" were proposed to aid others (i.e. this research) in developing designette implementations.[16] These ten characteristics for successful designettes are:

1. Clearly stated learning objectives and learning outcomes within a subject area (science, engineering science, mathematics, humanities, arts, social sciences), within a design process, or within a skill set
2. Intrinsically motivating, interesting, and fun activity
3. Open-ended activity with no single "correct" answer
4. Innovation focus
5. Need-based, well scoped, empowering, and motivating problem
6. Opportunities to ideate, explore design variables, explore the aesthetic, theme, explore economic or policy issues, explore ergonomic features, or some combination
7. Prototyping of ideas, at least virtually as part of a simulation, or physically as a concept or functional model
8. Relatively low-cost materials for creating prototypes[21, 22, 23, 24]
9. Implementing technology, such as layer-based manufacturing/rapid prototyping equipment, for quickly transforming ideas into reality,[25, 26] and
10. Forums to experiment with, test, or compete with generated designs

These ten characteristics were considered in the development of the current research.

There have also been extensive reviews of different formats and delivery methods of design education.[10, 16, 27] Through those and the direct experience of the authors, it was found that there are many approaches to the delivery of design education in capstone. As discussed in earlier sections of this paper, capstone design experiences can take the shape of one and two semester courses. Introduction of design process steps can take the form of lecture, case study, design exercises, textbook reading, process summaries in advance of application, and other approaches. The capstone projects themselves also vary widely within each institution making comparisons between projects and across domains difficult. There is research currently being conducted to provide a framework of understanding for different capstones.[28] Its goal will be to determine if

---

[a] Originally, designettes were referenced as "designiettes" or "designettes."[16] The spelling focused on "designettes" in subsequent publications[17] by the original author.

there are correlations with student learning outcomes and a suite of capstone characteristics (e.g. length, team size, funding type, degree of constraints, system level, agility of design process, etc.). This paper's incorporation of a designette would represent one aspect of the suite of capstone characteristics that should be considered in the framing of future offerings.

The current research is also a continuation of previous research in the area of mini-designs, which were highly related to the concept of designettes. On the emergence of the concept of designettes, it was realized that mini-design efforts were largely the same in intent as a designette and that the latter provided a more robust framework of understanding and assessing the effects of their implementation. In the previous study on mini-designs, a comparison of the incorporation a small mini-design experience at the beginning of capstone was assessed for its effectiveness. The use of mini-designs was shown to create students with a "more holistic understanding of the design process," and achieve a "slightly more rapid increase in understanding." [8, 19]

The duration of designettes has been studied previously.[8] Versions of the designette that took approximately 3 hours, 6 hours and 10 hours of student time were compared. The advantage of the shorter designette is simply that the design team can address the actual capstone project sooner. However, the effectiveness of the designette and the extent to which the design process content needed to implement the designette can be properly delivered to the students may be compromised by a shorter designette time allocation. The research indicated that a medium time commitment for the designette provided the best overall experience for the students.

3. Research approach

Our ongoing research applies the concept of the designette to our two-semester capstone education model. In previous work, the designette's project content was defined by the faculty and assigned to all of the student design teams (typically 8-10 distinct teams). The teams are formed from 56 senior-level engineering students. Most teams have a majority of mechanical engineering students with a minority of systems engineering or electrical engineering students. The designette was a well-scoped design problem that was unrelated to the students' capstone, long-term, real-world project. In this work, we sought to discover if it would be advantageous to assign a designette that is a small portion of the long-term, real world project, or to continue to assign a artifical, unrelated designette project. It is with this in mind that we developed our research question:

> Research Question:
> What are the advantages and disadvantages of relating the designette project to the larger capstone project, compared to using a designette project that is unrelated to the larger topic?

Nine capstone design teams were separated into groups, with four groups receiving "related" designette projects, and five groups receiving "unrelated". While a full design process will include numerous steps, our implementation of the designette included a subset of commonly accepted design methods. The methods we included in the designette are: Customer Needs Analysis, Functional Decomposition, Ideation, Concept Selection and Prototyping.[29] For all teams but one external-department team, the designette experience spanned the first three class lesson periods, with a fourth lesson used for final presentations of the designette. The external-department team used four lessons for the design material and a fifth lesson for the final presentations. The course uses a two-hour class period, so there was time for the faculty to present lesson content with time remaining for the students to work in teams on their project. The lessons were as follows:[b]

Lesson 1 – Content provided on Customer Needs data collection/analysis, designette introduced
Lesson 2 – Content provided on Functional Decomposition, Ideation, Decision Analysis and Prototyping (Customer Needs results due)
Lesson 3 – No content provided–team work time (Functional Decomposition & Ideation due)
Lesson 4 – Designette Final Presentations (prototypes & design analysis due)

In total, approximately 90 minutes of lecture-based lesson content was presented to the students, with the remaining ~ 4.5 hours of class time available for the teams to work on their designette projects, in addition to any time spent outside of class. It is noteworthy which five design process steps were selected for presentation to the students as part of the abbreviated design process, as these could certainly vary, and might affect the results. All teams remained the same between the designette and their larger capstone project, in part to limit this as a factor in assessing the designette's effects, and to gain the benefit of having the teams be complete with their team forming dynamics by the end of the designette phase. Both types of teams were expected to produce a complete mock-up, or basic functionality prototype, at the conclusion of the designette to be presented with their design presentation.

The topics for the "related" designettes varied by team, depending on the subject of their larger capstone project, so they will not be described here in great detail. In general, the students were assigned an appropriately scoped topic related to their larger, sponsored project by their faculty advisor. For example, consider the designette used by a capstone team whose long-term project is to develop technology to fight bridge corrosion. Their designette was to design an environmental chamber, on the order of one cubic meter in size, which could be used later for prototype testing of their real-world project solution concepts. The hypothesized advantage of using a related designette topic is that research and work performed on the designette contributes to the larger project. Potential disadvantages are that (a) the designette is harder to be ideally scoped by faculty to provide the optimal learning experience, (b) the abbreviated and time-constrained nature of the designette may falsely create low student expectations as to the required quality of work, (c) time-constrained work may find its way into the larger project without iteration or refinement, and (d) students may avoid taking risks due to the "gravity" of the sponsored project. Note that although the list of potential disadvantages of the related project is rather long, the main objection to implementation of designettes in general is that it takes time away from the actual project. This objection is neutralized when the designette project is related.

[b]The alternate department implementation of the designette followed an extended schedule (i.e. 5 lessons) as described in section 4.3.2).

The “unrelated” designette topic, created by the faculty, was for the students to design an improved student dorm room, with no other constraints provided. This topic had no relation to any of the long-term capstone projects. The hypothesized advantages of using an unrelated topic are that (a) the topic can be ideally scoped to provide a learning experience that is adequately well-defined while still providing opportunities to innovate, (b) a topic can be used that is potentially very interesting, motivating, easier to prototype and/or familiar to the students, thus requiring less background research, (c) certain elements of the design process can be made easier or more direct to complete, such as collecting customer needs data (by providing contrived but representative data directly to the students), (d) the abbreviated and time-constrained designette processes will not feed into the larger project in terms of quality or iteration and (e) students likely feel freedom to take risks. The hypothesized disadvantage of the unrelated designette is that the team time spent on the project and results produced do not directly contribute to the long-term project. Thus, the student dorm room project was selected because the students had a strong personal interest in it (being potential stakeholders / customers themselves), they had extensive background knowledge of the current product, customers were readily available and their solutions could be easily prototyped.

Advantages and disadvantages of the unrelated/related designette approaches were observed from a variety of data sources. First, all students and faculty advisor were invited to provide feedback on the designette by way of a feedback form. The form included 26 subjective questions from which respondents could indicate agreement through a Likert seven position response scale. Table 2, Section 4.1, lists the questions. The form also included five additional questions asking what should be emphasized more, how long the designette should be, what the best part was, areas that should be changed, and a request for other comments.

The second data source obtained was faculty evaluation of the designette final presentations. First, all 11 faculty advisors were invited to observe all nine project team presentations, where comments were collected on assessment forms aligned with the five major design steps. Following the presentations, two faculty members separately reviewed the assessment form comments from all evaluators. The table below represents an example of the initial conversion of advisor comments to coarse objective indicators (i.e. +1 for generally remarkable good performance in an area, 0 for generally average or sufficient performance, and -1 for remarkably poor performance in a particular area).

Table 1: Example data table for designette final presentations to faculty

		Faculty evaluator											
	Design Step	1	2	3	4	5	6	7	8	9	10	11	AVG
Project team A	Customer Needs	0	1	-1	0	-1	0	1	1	0	1	0	0.18
	Functional Description	0	-1	-1	0	1	0	0	-1	0	-1	0	-0.27
	Concept Generation	0	0	-1	0	0	1	1	0	0	1	0	0.18
	Concept Selection	0	1	-1	-1	0	0	1	1	0	1	0	0.18
	Prototyping	1	1	1	0	0	-1	0	1	0	0	0	0.27
	Average:	0.2	0.4	-0.6	-0.2	0	0	0.6	0.4	0	0.4	0	**0.11**

Data from faculty reviewers was combined to average out any latent perception error of the assessment form comments. Following this process, the averages observed across all Unrelated and Related projects were combined for further reporting in Section 4.2.

Finally, qualitative observations from faculty advisors were collected and are reported in Section 4.3. Faculty advisor feedback form comments and direct observations of the authors will be presented. Also, as a way of exploring the variable of department-specific execution, the designette was also implemented in a separate department's capstone project to observe differences and similarities. Not only will these results help provide context to conclusions of the present research, but also serve to shape areas of exploration in future research.

4. Results

Results are organized in three subsections based on the method in which observations were gathered. First, data from student and faculty feedback forms is presented along with some summary observations. Second, data and observations are provided on performance of the various project teams during their designette final briefs. Finally, qualitative faculty observations are presented from a variety of projects, including one project outside of the primary department.

4.1. Faculty and student polling results

Following the conclusion of the designette project, all participating students and advising faculty were asked to provide feedback on the experience. Of a total pool of 56 students and 11 faculty members, there were 51 and 11 respondents respectively. This represents a 91% and 100% response rate respectively. Table 2 displays the response data to the 7-position Likert scale agreement questions (1 = strongly disagree, 4 = neutral, 7 = strongly agree). Data represents both student and faculty responses.

Table 2: Combined faculty and student feedback on the designette experience (Likert 1-7 scale). *For the final column of delta values, positive = unrelated designettes did better, negative = related designettes did better.*

Questions	Combined Reponses		Unrelated Designette		Related Designette		Unrelated -Related Delta
	Mean	StDev	Mean	StDev	Mean	StDev	
I think the appropriate length (# of lessons) for the mini-design project is [0...20 as available inputs].	5.1	1.7	5.57	2.06	4.60	1.08	0.97
The Designette is a valuable component of the capstone design experience.	5.2	1.5	5.58	1.43	4.86	1.58	0.72
The Designette should have been given more time (additional lessons)	4.6	1.9	4.90	1.58	4.29	2.11	0.62
Our team had enough understanding of the design subject to make progress within the time constraints.	5.4	1.1	5.61	0.56	5.11	1.40	0.50
The Designette helped me understand the "**Concept Selection** (Pugh Analysis)" step in the design process	5.4	1.1	5.67	0.96	5.18	1.22	0.49

Questions	Combined Reponses		Unrelated Designette		Related Designette		Unrelated -Related Delta
	Mean	StDev	Mean	StDev	Mean	StDev	
The Designette did not go deep enough into the 5 design tools/steps.	3.4	1.5	3.57	1.50	3.15	1.46	0.42
The Designette improved my understanding of the capstone design process.	5.6	1.0	5.77	0.92	5.36	1.10	0.42
The Designette motivated me through competition with the other teams (if applicable)	3.8	1.6	3.97	1.70	3.67	1.56	0.30
The Designette helped me understand the "**Concept Generation**" step in the design process	5.4	1.1	5.57	0.97	5.29	1.24	0.28
The Designette was relevant to me personally	4.8	1.7	4.90	1.60	4.64	1.83	0.26
The Designette helped me get to know my team	6.0	1.1	6.10	1.04	5.89	1.23	0.20
The Designette helped me to get to know my faculty advisor(s)	5.8	1.3	5.89	1.23	5.70	1.33	0.20
The Designette provided a design process framework that I can rely on in my full project.	5.4	1.2	5.50	1.17	5.32	1.25	0.18
Our team was able to collect customer needs data relevant to the mini-design in a timely fashion.	5.2	1.5	5.23	1.52	5.19	1.52	0.04
The Designette had the right depth of instruction for the design process/tools.	4.8	1.2	4.84	1.04	4.82	1.47	0.02
The Designette helped me understand the "**Customer Needs Analysis**" step in the design process	5.4	1.3	5.37	1.38	5.36	1.25	0.01
The problem statement was clear, and our team knew how to proceed in solving the problem.	4.7	1.4	4.71	1.40	4.70	1.51	0.01
The Designette helped me understand the "**Functional Description**" step in the design process	5.2	1.2	5.13	1.28	5.21	1.23	-0.08
The Designette was interesting	5.4	1.5	5.32	1.47	5.43	1.53	-0.11
The Designette had the right breadth of design process/tools (recall we covered 5: Customer needs, Functional Decomposition, Ideation, Concept Selection and Prototyping).	5.4	1.0	5.30	1.06	5.43	1.03	-0.13
I had sufficient time to prototype	3.8	1.4	3.65	1.56	3.93	1.21	-0.28
The Designette helped me understand the "**Prototyping Strategy**" step in the design process	5.1	1.4	4.97	1.43	5.29	1.27	-0.32
The Designette increased my motivation and enthusiasm	4.7	1.4	4.48	1.50	4.86	1.27	-0.37
The Designette should have been given less time (fewer lessons)	2.3	1.3	2.06	1.12	2.46	1.50	-0.40
The design subject led to concepts that were able to be prototyped within the Mech Lab in a timely fashion.	5.1	1.4	4.62	1.33	5.56	1.25	-0.94
The Designette helped me to know the capabilities of the Mech Lab	3.6	1.5	3.04	1.30	4.14	1.56	-1.10
The Designette helped me become familiar with my team's full/sponsored project	3.1	1.8	2.23	1.36	4.04	1.72	-1.80

From this data and subsequent clarifying discussions, several observations were made.

- "Unrelated" teams typically agreed more strongly that the designette…
    - …was a valuable component of the capstone experience,
    - …should have been given more time (additional lessons),
    - …the team had enough understanding of the design subject to make progress within the time constraints[c], and
    - …the designette better helped them understand the Concept Selection step in the design process.
- "Related" teams typically agree more strongly that the designette…
    - …helped them become more familiar with their team's full/sponsored project,[d]
    - …helped them know the capabilities of the Mech Lab, and
    - …the design subject led to topics that could be prototyped in the Mech lab in a timely fashion.
- Overall, the areas for both types of teams (speaking to the overall effectiveness of the designette concept) that had strong agreement were…
    - …that it helped them get to know their team,
    - …helped them get to know their faculty advisors, and
    - …it improved their understanding of the capstone design process.
    - Also of note is that the general averages for the 5 design steps are positive (i.e. mildly agree on average).
    - The average length of the designette desired was 5.1 lessons (StDev 1.7 lessons)

4.2. Observations on designette final presentations

The next observable data used were the faculty assessments of the final presentations for each project's designette. As described in Section 3, the qualitative comments from all faculty on the students' performance in the five major design steps were used to determine a general performance assessment for each team. With each project team identified as either "related" or "unrelated" to their larger capstone project, scores were averaged within each subgroup. Table 3 shows this roll-up of averages for the "related" and "unrelated" team performance in the five key design steps. Note, this data does not include results from the alternative department implementation of the designette. Recall that the rating numbers are: +1 for generally remarkable good performance in an area, 0 for generally average or sufficient performance, and -1 for remarkably poor performance in a particular area.

[c] This result supports an initial hypothesis (section 3) that the unrelated designette can "…be ideally scoped to provide a learning experience that is adequately well-defined while still providing opportunities to innovate,…"
[d] This result supports an initial hypothesis (section 3) that the related designette has an advantage of having "…research and work performed on the designette [that] contributes to the larger project."

Table 3: Summary of faculty observed proficiency of major design steps in the designette final presentations

Design Steps	Unrelated Designette Mean	Related Designette Mean	Unrelated-Related Delta	
Customer Needs	0.45	-0.18	0.63	positive = Unrelated did better
Functional Description	-0.31	-0.03	-0.28	negative = Related did better
Concept Generation	0.28	0.05	0.23	
Concept Selection	0.20	-0.36	0.56	
Prototyping	0.28	0.32	-0.03	
avg	0.18	-0.04	0.22	

From presentation sub-topic comparisons unrelated designette teams do better, especially in the areas of Customer Needs and Concept Selection, while related designette teams did slightly better in Functional Description. For the design step of Customer Needs, the unrelated teams may have performed slightly better due to a perception that those teams needed to explore and report the topic with stakeholders more than those on related designettes, who may have felt like their topic was already defined and requirements known. For the design step of Concept Selection, the unrelated designette teams may have felt a stronger necessity to present their selection method due to having the freedom to explore many different concepts before being expected to select one prior to a relatively simpler prototyping phase. Therefore, their down-select process was of more interest and allowed more focus on those teams. For the related teams, the slight performance advantage in the Functional Description step may be a result of a strong desire by those teams to document the actual functional behavior of their system in order to move into well-justified progress on the next steps, knowing that they would need time towards prototyping.

In addition to the above inferences and speculations about possible causes of the performance differences, there are still a lot of confounding factors that could explain the differences in performance averages. Past experience with the design steps varied among team members based on student major (e.g. Mechanical Engineer vs. Systems Engineer). Team faculty advisors have minor preferences towards different design steps, and that could sway a team's effort towards particular tasks. There is also the factor that the numbers above are based upon assessments of qualitative remarks made by faculty following the team presentations.

4.3. Qualitative Faculty Observations

Another data source used to assess the advantages and disadvantages of the related/unrelated implementation of designettes is the collection of faculty qualitative observations. These observations are both from faculty that implemented the designette within the primary department of the current research, and a separate department so that the department culture might be better isolated as a variable. Section 4.3.1 includes summary comments from both the faculty feedback sheets as well as comments from the authors. Section 4.3.2 includes remarks from the faculty advisor that implemented an unrelated designette outside of the primary department.

4.3.1. Observations from project advisors within the primary department

As part of the faculty feedback forms, faculty members were asked how the designettes could be improved. Many of the comments dealt with the major design steps that were presented. When asked what area of the designette should be emphasized more, responses varied. In the 11 respondents, all five of the major design steps were mentioned as an area needing more emphasis. This shows the diversity of faculty advisors that implemented the designette, and also the differences in perception of priority of design step effort.

When faculty members were asked what the best part of the designette was, the responses varied, but the most common response centered on the idea of letting the students jump right in, “get their hands dirty”, and be creative. This is a distinctly inductive teaching strategy. This highly experiential way of teaching the design steps is commonly understood to be a strength of the method, and it continues to emerge as the best part of the approach. Other faculty comments highlighted the early presentation of the students’ work and the ability to observe other teams’ presentations as well. This was highlighted as a strength when compared with previous capstone models that do not have presentations or design feedback as part of the course until much later in the course (e.g. preliminary and critical design reviews).

Faculty members offered several ideas on what should be changed on the designette. Several members indicated a desire to have more details and common guidance provided on the design steps. Some advisors were very comfortable with the design steps and preferred more one-on-one time with their team; however other faculty advisors saw a disadvantage in a common designette competition model when different teams had different levels of design step instruction.

Overall, faculty advisors view the designette approach positively. Several advisors of the related designette teams remarked that they liked the ability to tailor their designette to be directly beneficial to their larger project. Likewise, faculty advisors of the unrelated designette teams appreciated the ability to have their teams experience the rapid development cycle in a low-threat, innovative atmosphere, and untethered to longer term impacts of their designette design decisions. Ultimately, the advantages and disadvantages observed in this study are meant to inform a potential designette administering program, such that the right factors can be chosen for the desired outcomes.

4.3.2. Observations from a project advisor outside the primary department

The unrelated designette assignment (redesign of a student dorm room) was given to a capstone team outside of the primary department. The team was comprised of seven systems engineering students. The team’s larger project is the development of a system to detect the presence of the Ips Beetle in local forested areas. The project was a multi-year project spanning three years in which customer need statements and project objectives, as well as conceptual design approach, were determined by earlier classes. Although the designette assignment was unrelated to the Ips Beetle project, it was given to the class to take them through an accelerated conceptual design phase and gain experience on a quick mockup delivery suspense prior to picking up where previous year’s Ips teams left off.

The project team was given five lessons to answer the ill-defined problem "today's dorm room is not sufficient in meeting the needs of a modern student." During the five lessons, the project team was divided into three sub-teams. Lesson 1 introduced the designette and the problem statement. Each sub-team derived a list of requirements and briefed the rest of the class on Lesson 2. Lesson 3 involved briefings on the functional capabilities of the "modernized dorm room" with component lists briefed during Lesson 4. During Lesson 4, the three sub-teams were merged back into one team and given the task to create a physical mockup of their design solution. The physical mockup was presented during Lesson 5. The course instructor provided feedback during each lesson with a summary discussion at the conclusion of the designette exercise.

An observation made during the designette is the impact of requirements development on a project's success. Students linked a majority of their "struggle points" to careless requirements. The short duration of the designette experience highlighted the complications which poorly defined requirements have on a system's design. By "rushing to the solution," the sub-teams struggled with subsequent design phases. Overlooked requirements led to unidentified functional capabilities and incomplete component lists.

The short duration of the designette also led the students to another common issue on system development; a lack of project leadership. The sub-teams became so focused on task accomplishment; they lost sight of the purpose of their activities. The overall objective of the designette was forgotten as the students only looked at their efforts from a tactical view. The hindrances of poor management became apparent when the three sub-teams joined together for the final physical mockup delivery. Following the final presentation, the students identified the lack of focus as a main detractor from producing a high quality and complete product.

While the designette was unrelated to the Ips Beetle project, the lessons learned during the activity were ideal in foreshadowing complications which the team would experience when they continued the semester working on the capstone project. Several times, poorly defined requirements would slow down the design process of the team and resulted in delayed system tests. One example of such a delay was the team unnecessarily spent three months redesigning a payload housing box because of confusing requirements definition. Subsequent testing of the housing box verified initial requirements were met. Weak project management also plagued the team throughout the semester. Poorly developed schedules, delegation of activities and almost non-existent communication of team member contributions have put the project several months behind schedule.

The initial exposure to sound systems engineering practices the designette provided to capstone teams shed light on needed skillsets and organization. The students identified the importance of these activities. Forgetting all of the valuable lessons learned during the designette experience once the students began work on their capstone project offered excellent teaching opportunities. The unrelated nature of the designette to the actual capstone project may be part to blame; however, the instructor feels this is a common characteristic of undergraduate engineers. Instead of holding the designette at fault, the experiences gained from it were used as reminders to the student team on proper design efforts.

5. Limitations

The study has a few limitations in its implementation and application. The sample sizes of faculty and students were large within the implemented departments and likely representative of the research institution; however, care would be needed in extrapolating the results to other institutions without larger and more diverse data sources. Also, not all variables were possible, or attempted, to be controlled. Factors such as the capstone topics, designette topics, team composition, faculty backgrounds were observed, though not strictly controlled in developing the presented results and conclusions.

6. Conclusions

Capstone design courses are the culminating experience of the undergraduate engineering education model. In some curricula, where deliberate design education for engineering application is absent or minimal prior to capstone, the designette concept shows great promise for introducing the major design steps in a rapid, scoped, experiential learning method. For the past four years, we have explored various factors that shape the designette experience. The current research sought to explore an additional factor –relatedness of the designette to the larger capstone project.

The advantages and disadvantages of the related/unrelated designette approach were of primary interest to the current research. Through use of several data sources, several observations were made that address some initial hypotheses of this research and can be compared to previous research on the characteristics of successful implementation of the designette.[8] From student and faculty feedback, it was observed that unrelated designettes highly valued the designette experience, and the teams felt the topic selected was scoped appropriately to make progress. The unrelated teams also seemed to perform slightly better at the Customer Needs and Concept Selection design steps. An advantage of the related designette was shown to be that the teams were able to better understand their larger/sponsored project. The related teams also seemed to do slightly better at performing and presenting their Functional Description design step. It was observed that the average desired length of the designette experience was 5.1 lessons, which supports previous research[3] on the appropriate length of implementation. It was also observed that both versions of the designette continue to support teams getting to know each other, their faculty advisor, and the overall capstone design process, in addition to learning the five major design steps used in this study.

Future research in designettes may continue exploring the factors which make them a success in enhancing design education. Factors such as domain implementation and level of guidance on the steps provided are of interest to the authors. Comparison of existing data to implementation at more institutions and settings are also of interest and will improve our understanding of how designettes can continue to be an asset to design and engineering education.

Acknowledgements

This material is based on research sponsored by the United States Air Force Academy under agreement number FA7000-12-2-2005. The US Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation thereon. This work is also based research sponsored by the SUTD-MIT International Design Centre (IDC, idc.sutd.edu.sg). The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the United States Air Force Academy or the US government.

Bibliography

1. Steffe, Leslie P., and Jerry Edward Gale, eds. (1995). *Constructivism in education*. Hillsdale, NJ: Lawrence Erlbaum.
2. Dutson, A. J., Todd, R. H., Magleby, S. P., & Sorensen, C. D. (1997). "A Review of Literature on Teaching Engineering Design Through Project Oriented Capstone Courses." *Journal of Engineering Education*, 86(1), 17-28.
3. Dutson, A., Green, M., Wood, K., & Jensen, D. (2003, June). "Active learning approaches in engineering design courses." *In Proceedings of the 2003 ASEE Annual Conference and Exposition.*
4. Engineering Accreditation Commission, "Criteria for Accrediting Engineering Programs, 2014 – 2015," Accessed 30 Jan 2015, Available: http://www.abet.org/.
5. Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). "Engineering design thinking, teaching, and learning." *Journal of Engineering Education*, 94(1), 103-120.
6. Wood, K. L., Jensen, D., Bezdek, J., & Otto, K. N. (2001). "Reverse engineering and redesign: Courses to incrementally and systematically teach design." *Journal of Engineering Education*, 90(3), 363.
7. Otto, K., Wood, K. L., Murphy, M. D., & Jensen, D. D. (1998, June). "Building better mousetrap builders: Courses to incrementally and systematically teach design." *In Proceedings of the ASEE Annual Conference and Exposition.*
8. Cory A. Cooper, Michael Anderson, Chad Bruce, Sarah Galyon Dorman, Daniel Jensen, Kevin Otto, Kristin Wood. (2015). "Designettes in Capstone: Initial Design Experiences to Enhance Students' Implementation of Design Methodology," *In Proceedings of the 122nd American Society for Engineering Education (ASEE) Annual Conference and Exposition*, Seattle, WA, June 14-17.
9. Howe, S. (2010), "Where Are We Now? Statistics on Capstone Courses Nationwide," *Advances in Engineering Education*, vol 2, no. 1.
10. McKenzie, L. J., Trevisan, M. S., Davis, D. C., & Beyerlein, S. W. (2004, June). "Capstone design courses and assessment: A national study." *In Proceedings of the 2004 American Society of Engineering Education Annual Conference & Exposition* (pp. 1-14).
11. Green, M., Jensen, D., and Wood, K. (2009). "Design for Frontier Contexts: Classroom Assessment of a New Design Methodology with Humanitarian Applications," *International Journal of Engineering Education*, vol 25, no 5.
12. Felder, R. M., & Silverman, L. K. (1988). "Learning and teaching styles in engineering education." *Engineering Education*, 78(7), 674-681.
13. Jensen, D.D. and K.L. Wood (2000). "Incorporating Learning Styles to Enhance Mechanical Engineering Curricula by Restructuring Courses, Increasing Hands-on Activities, & Improving Team Dynamics." In *ASME Publication and Presentation for the Award for the Most Innovative Curriculum for the Year 2000, Presented at the ASME Annual Conference*. Orlando, FL
14. Jensen, D.D., M.D. Murphy, and K.L. Wood. (1998). "Evaluation and Refinement of a Restructured Introduction to Engineering Design Course Using Student Surveys and MBTI Data." *In Proceedings of the ASEE Annual Conference and Exposition*. Seattle, WA.
15. White, Christina, Wood, Kristin, Jensen, Daniel. (2012). "From Brainstorming to C-Sketch from Principles of Historical Innovators: Ideation Techniques to enhance Student Creativity," *Journal of STEM Education*, vol 13, no 5, Oct-Dec 2012.

16. Wood, K. L., Mohan, R. E., Kaijima, S., Dritsas, S., Frey, D. D., White, C. K., ... & Pey, K. L. (2012). "A Symphony of Designiettes: Exploring the Boundaries of Design Thinking in Engineering Education." In *Proceedings of the 119th Annual ASEE Annual Conference & Exposition*, Paper AC2012-4004, San Antonio, TX.
17. Telenko, C., B. Camburn, K. Hölttä-Otto, K. Wood, and K. Otto. (2014). "Designettes: New approaches to multidisciplinary engineering design education." *Proceedings of the ASME 2014 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC/CIE 2014).* August 17-20, 2014, Buffalo, New York, USA.
18. Telenko, C., Wood, K.L., Frey, D., Dritsas, S., Kaijima, S., Tan, U., Moreno, D., Rajesh, M., Foong,S., and Pey, K.L. (2015). "Designettes: New Approaches to Multidisciplinary Engineering Design Education," *Journal of Mechanical Design (JMD)*, MD-15-1178, 2015.
19. Wahlquist, Joseph A., Jensen, Daniel D., Wood, Kristin L., Fitle, Kyle, and Carte, David. (2013). "Using Mini Design Competitions in Capstone," In *Proceedings of the 120th ASEE Annual Conference & Exposition*, Atlanta, GA, 23-26 June, 2013.
20. Otto, K., Camburn, B., Wood, K., Bouffanais, R., Kyoseva, E., Yee, L. H., ... & Mathur, A. (2014). Integrated 2D Design in the Curriculum: Effectiveness of Cross-Subject Engineering Challenges. *In Proceedings of the ASEE Annual Conference (Vol. 24).*
21. Camburn, B., Dunlap, B., Gurjar, T., Hamon, C., Green, M., Jensen, D., ... & Wood, K. (2015). A Systematic Method for Design Prototyping. *Journal of Mechanical Design*, 137(8), 081102.
22. Camburn, B., Dunlap, B., Linsey, J., Viswanathan, V., Jensen, D., Crawford, R., ... & Wood, K. L. (2013). Using Design Problem Characteristics to Build a Prototyping Strategy. *In Proceedings of the ASEE Annual Conference.*
23. Camburn, B. A., Dunlap, B. U., Kuhr, R., Viswanathan, V. K., Linsey, J. S., Jensen, D. D., ... & Wood, K. L. (2013, August). "Methods for Prototyping Strategies in Conceptual Phases of Design: Framework and Experimental Assessment." *In Proceedings of the ASME 2013 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (pp. V005T06A033-V005T06A033). American Society of Mechanical Engineers.
24. Camburn, B. A., Sng, K. H., Perez, K. B., Otto, K., Wood, K. L., Jensen, D., & Crawford, R. (2015, August). "The Way Makers Prototype: Principles of DIY Design." *In Proceedings of the ASME 2015 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (pp. V007T06A004-V007T06A004). American Society of Mechanical Engineers.
25. Perez, K.B., Otto, K.N., and Wood, K.L., "Crowd-sourced Design Principles for Leveraging the Capabilities of Additive Manufacturing," *In proceedings of the International Conference on Engineering Design (ICED)*, Milan, IT, July 2015, ICED15-396.
26. Jensen, D., Randell, C., Feland, J., & Bowe, M. (2002). A study of rapid prototyping for use in undergraduate design education. *In Proceedings of the 2002 ASEE Annual Conference*, pp. 7.113.1-7.113.15, Montreal, Canada, 16-19 June, 2002.
27. Marin, J. A., J. E. Armstrong, and J. L. Kays. (1999). "Elements of an optimal capstone design experience." *Journal of Engineering Education* 88, no. 1; p. 19-22.
28. Cooper, Cory A., Homan, Jeremy J., Fulton, Joseph M. (2015). "A multi-spectrum framework for characterizing interdisciplinary capstone design experiences," *Proceedings of the Conference on Systems Engineering (CSER)*, Hoboken NJ, Mar 18-19.
29. Otto, Kevin and Wood, Kristin. (2012). *Product Design: Techniques in Reverse Engineering and New Product Development*, Prentice Hall, Upper Saddle River, NJ, 2001.