21ST INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED17
21-25 AUGUST 2017, THE UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER, CANADA

UNDERLYING DESIGN MOTIVATIONS IN DESIGN METHODS AND OUTCOMES

Turner, Cameron; Agyemang, Malena
Clemson University, United States of America

Abstract

Design teams approach design problems with a set of explicit requirements derived from the problem, but also bring a number of implicit design requirements to the problem through the culture within which they work. We hypothesized that these influences affect how design teams approach design problems, and in particular, how teams define requirements and apply analogies to develop their designs. In this paper, we used a multi-section senior design course to place teams working on similar design projects for real customers in a situation where they were subjected to a cultural bias between a Design for Manufacture and Assembly culture versus a Design for Environment culture by the instructors of each section. During the class, the emergence of design requirements related to these biases were noted during design reviews. End of semester surveys further measured the perceived student significance of these cultural differences, as well as differences in how students used design analogies throughout their design projects. Based on the data collected, differences in design culture affect the design process and methods used by the design teams.

Keywords: Design for X (DfX), Decision making, Design process, Human behaviour in design

Contact:
Dr. Cameron Turner
Clemson University
Mechanical Engineering
United States of America
cturne9@clemson.edu

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 21st International Conference on Engineering Design (ICED17), Vol. 8: Human Behaviour in Design, Vancouver, Canada, 21.-25.08.2017.

1 INTRODUCTION

With every design, there are always direct influences that dictate the design methods and outcomes. For novice designers, such as engineering design students, or experienced engineers, these explicit influences are oftentimes initiated by the consumer or end user. These explicit design influencers often include information on the design's function, form, and use, and act as guidelines for the designer. This information influences the direction of the design process and the design outcomes. In addition to explicit design influencers, there are underlying design influencers that strongly and passively drive the design methods and design outcomes (Shrnhue et al., 1997).

Underlying motivations or influencers, occur because of the culture within an organization, the designer, or the consumer. These underlying motivations also influence design methods, the design process, and the design outcomes or the final design. Underlying design motivations can also influence how the designer describes the design to the end user for their understanding (Haponava and Al-Jibouri, 2010; Linsey and Viswanathan, 2010).

Though there are variations in the design process, there are five common widely accepted iterative steps in the design process (Haik et al., 2010; Pahl et al., 1996; Ertas and Jones, 1996):

1. Clarification of Tasks.
2. Concept Generation.
3. Design Requirements.
4. Embodiment Design.
5. Detail Design.

With these tasks being the main steps in the common design process, underlying motivations on the designer will not influence the steps taken, but rather influence what is conducted and what tools are used within these steps. Culture of the designer and the organization that the designer is working in are the main influences that create underlying motivations on design methods, design outcomes, and how they describe the design. However, the dynamics of designer culture, where it is reflected, and how to capture the presence of underlying influences is it not quite understood (Bucciarelli, 2000). This preliminary research intends to begin to understand how underlying motivations influence the design process. This work investigates if and where underlying design motivations influence design methods within the design process, design outcomes, and design description to the end user used by the designer.

2 THEORY

Underlying design motivations influence the design methods used, design outcomes, and how the designer describes the final design to the end user. However, how and where underlying design motivations influence design methods and outcomes is not understood. Underlying design goals are driven by the culture of the designer as well as the organization the designer works within. With the main steps used in the design process being the same for all designers, underlying motivations acting on the designer(s) will not influence the steps taken in the design process, but how certain steps are executed such as use of certain design tools and methods. If the explicit design goal is the same for a group of designers, but the underlying motivations acting on said designers are different, the impact, if any, will be reflected in the common components of the design process. All designs undergo the design process, the design outcome, and the process of describing the final design to the end user. If there are two distinct underlying motivations that acting on different designers or design teams, the differences and similarities of the implications of the motivations will be reflected if the design process, final design, and methods used to describe the design to the end user are compared.

Design for the Environment (DFE) and Design for Manufacturing and Assembly (DFMA) are two common underlying motivations of design companies (Chowdary and Harris, 2009). DFE is environmentally conscious design, acknowledging the way the product may positively or negatively impact the environment and taking that into account of the final design and/or design process (Fiksel, 2009; Giudice et al., 2006). DFMA is manufacturing cognisant design that lets manufacturing concepts and principals drive the final design and/or design process, focusing on relationship between parts, number of parts, and assembly (Ashley, 1995; Constance, 1992; Boothroyd et al., 1994). These design motivations influence the design methods, deign outcomes, and how the final design is influenced by, but how? And to what degree does this influence the design? Is a personal influence or an organizational driven influence more significant? Are there any patterns in design practices from a given underlying motivation and can this be mapped to predict the design outcome in an automated way? How and where underlying motivations influence the design methods, outcomes, and description of the design can be evaluated if a group of designers are given the same explicit design goals, but have two distinct underlying motivations acting on them.

Studies of the activities of designers indicate that previous experience is used to identify solutions to many design problems (Bucciarelli, 2000; Purcell and Gero, 1996; Pahl et al., 1996; Cross, 2001). One process abstracts the design problem to a level that allows other related solutions to be identified (as analogies) and then de-abstracts the analogies into solutions specific to the design problem. This process of abstraction and de-abstraction with analogies is commonly used by the design engineers during development of a design (Christensen and Schunn, 2007; Ball, 2004). Not only are analogies used in the design process, but they are used to describe the design to the end user. The use of analogies in the design process, outcomes, and the description of the final design can be assessed to highlight any potential trends. This study highlights how underlying motivations influence the design methods, final design, and description of the final design, as well as, how analogies are used in these three aspects.

3 METHODOLOGY

To evaluate the influence of underlying motivations on design methods, final design and final design description, a study was conducted of an upper lever undergraduate Mechanical Engineering design course. The course was taught by two professors and made up of two separate classes. One class met weekly on Monday and Wednesday, and the other class met weekly on Tuesday and Thursday. For simplicity, the Monday-Wednesday class will be referred to as Class A, and the Tuesday-Thursday class will be referred to as Class B from this point forward.

Students of both classes were junior and senior level Mechanical Engineering undergraduate students. The course was on introductory level mechanical engineering design. Both classes were taught by both professors, but Class A was led by a professor who and Class B was led by another. Class A's professor had no knowledge of the study, but it was assumed as a traditional Mechanical Engineering professor, the lectures were taught if DFMA underlying influencers. Class B was led by a professor her intentionally, in the scope of the study, taught with DFE underlying influences on the class. The students were taught lessons on the design process, with the given DFE and DFMA influences throughout the semester representing underlying influencers. This was used to create a range of underlying design influencers providing the capability to pinpoint if the influence came from an organizational level (the classmates and processors), or from an individual level.

Early in the semester, each student in Class A and B was tasked with a team project. There were given the task to join in teams of 6 to 7 students. Once the teams were formed, each team was partnered with one grade school teacher of grades ranging from 2nd to 7th grade. They were instructed to provide the teacher's class with a design that taught a lesson from the teacher's science curriculum. This resulted in 21 teams being formed in total for Class A and Class B. Each team was assigned a teacher, resulting in 21 grade school classes. Class A had 11 teams of 6 or 7 students and Class B had 10 teams of 6 or 7 students. Class A consisted of teams 11 through 21, while Class B consisted of teams 10 through 10. An example of the design teams and their assigned the grade school teacher's class grade, and design focus is listed in Table 1.

Table 1. Class B Teams and Associated Target Grade Level and Design Focus

Team	Grade	Focus	Team	Grade	Focus
1	2nd	Forces, magnets, and solids & liquids	6	5th	Forces and Motion
2	5th	Forces, friction and impulses	7	4th	Forces and Motion
3	5th	Pushes and Pulls	8	5th	Pushes and Pulls
4	2nd	Pushes and Pulls	9	4th	Irrigation System for Future Greenhouse
5	5th	Forces and Collisions	10	7th	Renewable Energy

Over the course of the semester, Class A and Class B would meet twice a week on their designated class days, once for their design lecture, then once for their design reviews. The design review was a session were teams would formally present the status of their design in the systematic design format (Pahl et al., 1996). They provided information on their goals, design requirements, status, and future work. Due to the capacity of the teams in each class and time limitations, the purple and orange teams alternated presentations each week. During the design review, once the students presented on their status, they were provided feedback from the professors and other students.

At the end of the semester, a design expo was held for the grade school students and the mechanical engineering undergraduate students. In the design expo, undergraduate students were able showcase their designs. The grade school students received the opportunity to go to their assigned design team's design along with several other student team designs. The design reviews and the design expo were used as studies to evaluate how underlying design motivations influence design methods, final design, and how the final design is described. To do so, two themes were evaluated:

1. The use of analogies in the undergraduate student's design methods, outcomes, and description of the final design to the grade school students.
2. The influence of underlying design motivations in design methods of the students.

3.1 Capturing Use of Analogies in Student Design Methods and Lessons

Analogies are used by the designer in the design process for concept generation, as well as, post design development to describe the design to the end user. This can be strongly influenced by underlying motivations acting on the designer. To capture if analogies were used by the designers in the design process, Class A and Class B students were surveyed individually throughout the design expo. The surveys were given to the students as the beginning of the design expo, prior to the grade school students arrival, and were requested to be given back at the end of the day. The surveys were used to uncover if the undergraduate students knew what analogies were, if they used them throughout the design process, when they used them, and if they used analogies to describe the design to the grade school students.

To see if the use of analogies was effective in describing the design to the grade school students, the grade school students were surveyed post design expo. In the grade school class survey, we wanted to uncover if the undergraduate students used analogies to teach the design and lesson of the design as well as the effectiveness of the analogies used. The surveys captured if the grade school students understood the lesson and if the undergraduate students related the lessons to something in their everyday life.

Once the teachers arrived to the design expo, they were given the survey, one for each class, and asked to pose these questions to their students once they design expo was over. They asked each question to their class as a whole and recorded the number of positive and negative responses. Positives responses, "Yes", and negative responses, "No", where indicated by a hand raise. For open-ended questions, key word or phrase response were recorded by the teachers.

3.2 Capturing Underlying Design Motivations of Student Design Methods

To capture where and when underlying design motivations influence design methods and final design, the design process and final design of the undergraduate students were assessed. Over the course of the semester, Class B's design reviews were shadowed to quantify the number of occurrences any DFE influences were mentioned by each team. This included anything that related to design for the environment, sustainability, or anything in that realm. When something of the DFE sort was mentioned, it was tallied, and the context was documented. The occurrences during the undergraduate presentations were noted as well as any occurrences during the question and answer portion. This provided quantitative information on when throughout the course and design process DFE was mentioned as well as highlight any trends.

The design reviews provided quantitative information as to how many times DFE was mentioned by the undergraduate design teams, however, it did not provide qualitative data as to why and when they DFE or DFMA was used. To capture qualitative information on the influence of underlying motivations, a survey was given to the undergraduate design students during the design expo. The same survey as mentioned earlier gaged the undergraduate design students to uncover things such as why they chose certain materials, design function, design forms, and what or who was the motivating driver.

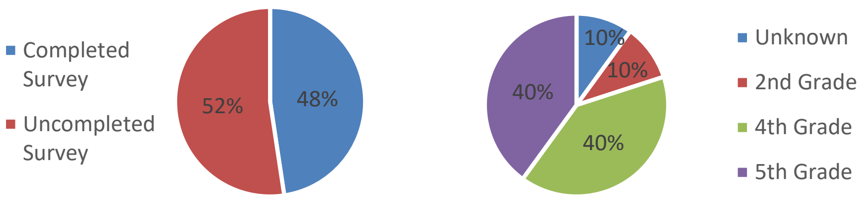
4 SURVEY PARTICIPATION

The undergraduate students were surveyed individually to highlight the influence of design culture. Data from the surveys was grouped by class; Class A and Class B. The survey participation for the undergraduate student surveys is listed in Table 2. There were 11 teams in Class A and 10 teams in Class B. Of the 11 Class A teams, 7 teams were surveyed, missing 4 of the 11 teams. Of the Class B teams, 100% of the teams were surveyed. In more detail, only 25 of the 67 students in the Class A were surveyed and 48 of the 60 students of Class B were surveyed. Low participation from Class A was due to it not being required for all the team members from one team to be present on the design expo day.

Table 2. Class A and B Student and Team Participation

Class	Team Participation	Percent Team Participation	Student Participation	Percent Student Participation
Class A	7 of 11	63.64%	25 of 67	37.31%
Class B	10 of 10	100.00%	48 of 60	81.67%

The grade school students were surveyed as a class, to uncover how they interpreted the lessons. The class survey participation for the grade school students is illustrated in Figure 1a. There were 21 grade school classes that attended the design expo. Of the 21 classes, 10 classes successfully submitted the survey at the end of the day. The design expo consisted of grade school students in 2nd, 4th and 5th grade. The participation of completed surveys by each grade is illustrated in Figure 1b.



a. *b.*

Figure 1. (a). Percentage of completed and uncompleted grade school surveys. (b). Grade coverage of completed grades school surveys

5 USE OF ANALOGIES IN STUDENT DESIGN METHODS AND LESSONS

5.1 Use of Analogies in Student Design Methods

The qualitative survey data indicated that some students were aware of what an analogy is. It also indicated that analogies were used in their design. Students were asked "what is an analogy". From here 72% of Class A was able to clearly define an analogy and 75.51% for Class B. The remaining students were unable to define and analogy, not because they did not know what one was, but because they answered the open-ended question with an analogy from their design as opposed to defining an analogy. If they answered this question with an analogy used in their design, it was counted as an undefined answer. The majority of Class A said that they did not use analogies in their design process or design, with 68% of the participants saying they did not and 32% saying they did. However, in Class B, 51.02 % of the participants said they did use analogies in the design process, and 48.98% of the students did not. When asked at which part of the design process they use analogies, the majority of the analogies were used in the concept generation phase for Class A and Class B. However, in Class B, a great number of students said that they used design analogies in all phases of the design process. The percentages of when analogies were used in the design process is illustrated in Figure 2. The blue columns in Figure 2 show Class A's percentage and the red columns shows Class B's percentage.

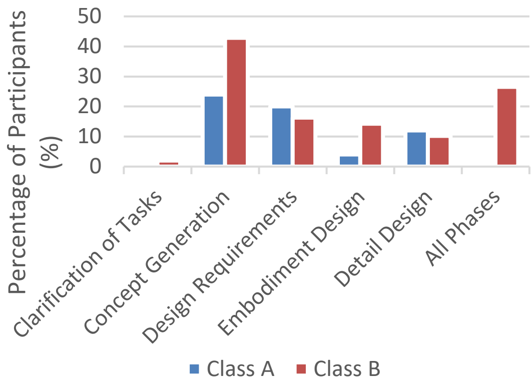


Figure 2. Percent of participants that indicated when analogies were used in the design process for Class A and Class B

When assessed on whether analogies were used on the form or function of the design, 72% of the Class A students did not use analogies in the functions or the form of the design. With Class B, however, 51.02% of the students used analogies in their design functions and 77.55% of them did not use analogies in their design's form.

5.2 Use of Analogies in Final Design Description

The survey data indicates that students used analogies to describe the design lessons to the grade school students. Analogies were not only used by the design students to teach the lesson, but they were also effective in helping the grade school students understand the lesson and retain the information. Percentages of the student participants that answered positively and negatively to the given survey questions are represented in Figure 3. The majority of the questions resulted in a 75% or more positive outcome. This suggests that analogies in design lessons was effective in teaching the lesson to the grade school students. Questions, "Can you repeat the lesson?", "Did the students make the lessons familiar to you?", and "Did the lesson remind you of something?", resulted in less than 100% of total participation because some of the surveys left that answers for those questions blank.

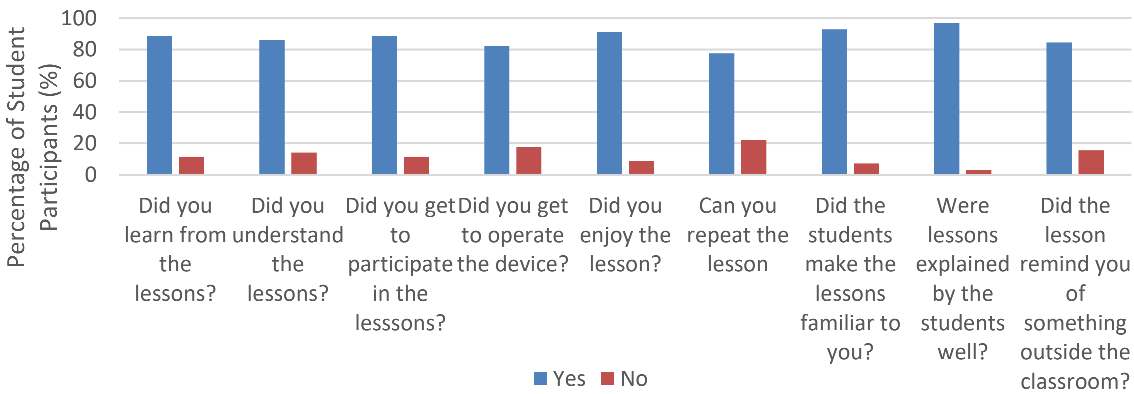


Figure 3. Percent of Yes and No answers from the grade school student survey

6 UNDERLYING DESIGN MOTIVATIONS OF STUDENT DESIGN METHODS

6.1 Assessment of Design Reviews

In Class B, there were a total of 8 weeks for design reviews shadowing with the Purple and Orange teams alternating every week. This weekly rotation resulted in a total of 4 design reviews for each team. The amount of times Class B mentioned DFE in regards to their design is graphed in Figure 4. Figure 4 also depicts if DFE was mentioned pre- and post-questions.

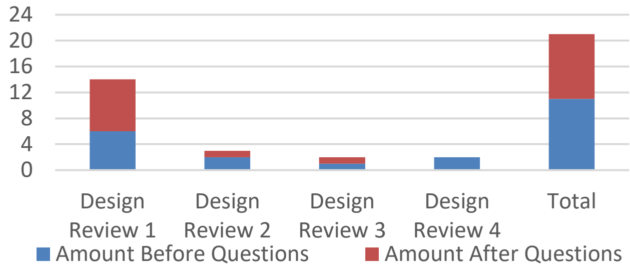


Figure 4. Occurrences when Class B mentioned DFE in relation to their design during design reviews

Earlier in the semester, more teams mentioned DFE, than towards the end of the semester. Some of the key words that were mentioned by the students and counted as DFE were; *"Reusable, recycling, reuse, minimize life cycle, consumable, sustainable design, minimize environmental impact, recycled wood, recycled materials."* These key words all revolved around the design having the ability to be easily recycled, or use of recycled materials. The occurrences of DFE mentions decreased throughout the semester. Based on the key words used earlier in the semester, "*recycled materials, reusable, low environmental impact*", the DFE occurrences during the design reviews dropped because the teams stopped explaining why they chose certain materials or design functions and forms. When explained why they chose certain materials, they mainly hinted towards the ease of material as being their reason for choosing it. Teams 6 and 10 asked for feedback on materials during the design review, suggesting that they want to use environmentally safe materials, or looked to classmates and professors for reassurance in their material selection. During the design review, many other teams asked for reassurance on their design's form, functions, and materials. This suggests that the opinion of the classmates and professors was greatly valued by the design teams. The design reviews alone were unable to capture if DFE was used in the design as well as who or what was the main influencer of DFE in the team's design because the limitations of depth in the design presentation. However, the reviews did suggest where in the design process and design form and function that could have been influenced by DFE. High mentions of DFE early in design reviews suggests that is there are underlying design goals within a group that they will not express within external presentations of the designs. This suggests the culture of DFE is assumed to be common sense or common knowledge, not needed to be shared in design reviews. To evaluate this hypothesis, teams and students were interviewed to capture any underlying motivations that may have been left out. If so, what were the reasoning for leaving this information out.

6.2 Assessment of DFE and DFMA use and Influences

To evaluate if the engineering design students considered DFE or DFMA, they were surveyed on their use of DFE and DFMA as well as the influences that encouraged them to use DFE or DFMA. Figure 5 depicts if Class A and Class B considered environmental benefits or manufacturability in the design. Class B considered environmental benefits more so than Class A not only in the design process but in the materials used. Only Class B considered environmental aspects in the forms and functions of their designs. However, Class B considered more manufacturing benefits in their design process as well as the materials, and design forms and functions. This could have been due to the low participation from Class B. When asked what materials, forms or functions were used for environmental benefits, the main answers were that same as the DFE key words mentioned in the design review; *"reusable, recyclable, and recycled"*. When asked what materials, forms or functions were used for manufacturing benefits, the main answers were *"ease and simplicity"*.

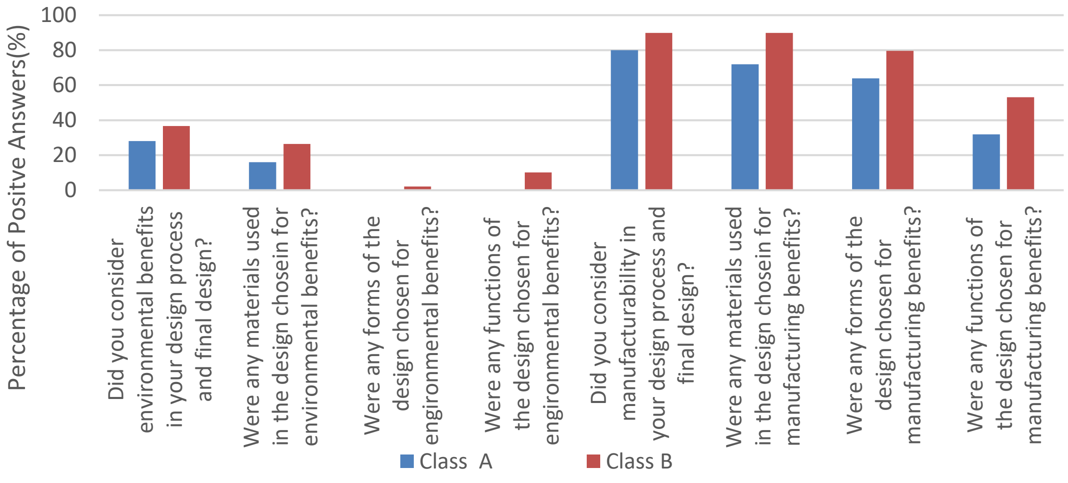


Figure 5. Percent of Positive "Yes" Answers to Survey Questions on DFE and DFMA for Class A and Class B

When DFE and DFMA were used in the design process for Class A and Class B was evaluated as well as the influences. Figure 6 illustrates were in the design process DFE was considered by Class A and Class B as well as who contributed to the influences. For Class A, if DFE was considered, it was mainly considered in the design requirements. However, for Class B, DFE was considered in all stages. Class A demonstrated a stronger influence for DFE from themselves, team members, and classmates, however, Class B indicated that their influences to use DFE came from all parties. The number of All influences suggests that Class B had a greater DFE influence in the classroom, teammates, themselves as well as professors.

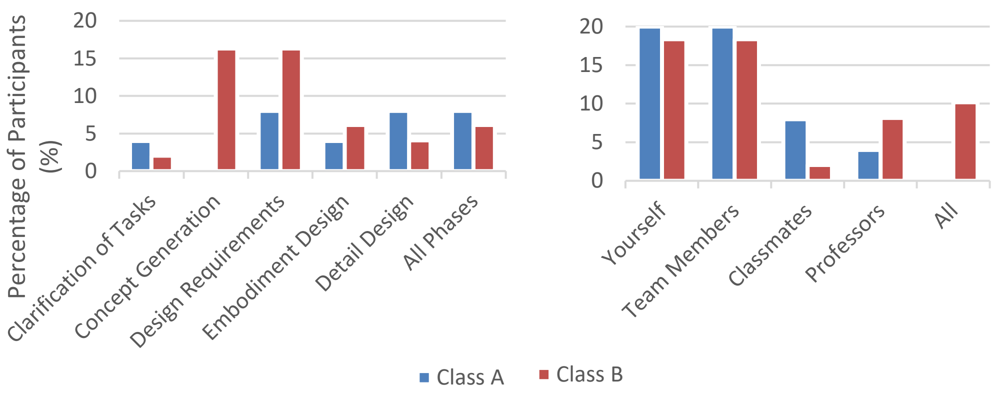


Figure 6. Percent of participants that indicated (left) when DFE were used in the design process and (right) who influenced the use of DFE for Class A and Class B

Figure 7 illustrates were in the design process DFMA was considered by Classes A and B as well as who contributed to the influences. For Class A, if DFMA was considered, it was considered in all aspects of design except clarification of tasks. This was the same for Class B. However, Class B considered, manufacturability more than Class A in all aspects except for design requirements. When asked were the influence came from for use of DFMA in the design, Class B demonstrated a stronger influence from themselves, team members, and classmates. However, Class A indicated that their influences to use DFMA came from all parties. The number of All influences suggests that Class A had a greater DFMA influence in the classroom, teammates, themselves as well as professors.

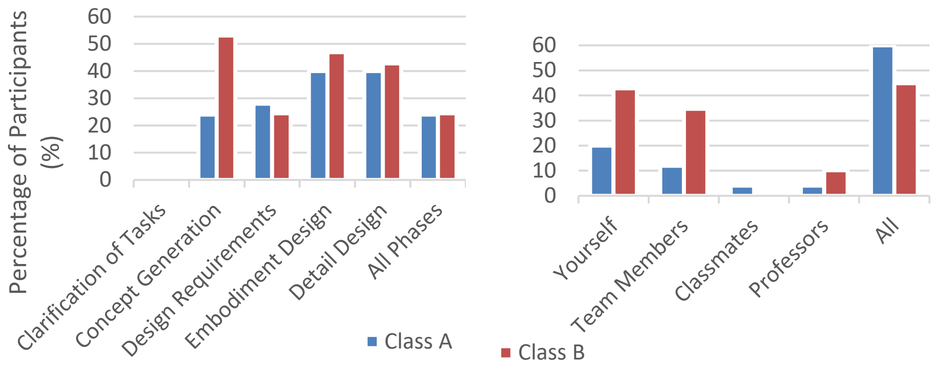


Figure 7. Percent of participants that indicated (left) when DFMA were used in the design process and (right) who influenced the use DFMA for Class A and Class B

7 DISCUSSION

Class A considering more manufacturing attributes in their design as oppose to environmental attributes, while Class B also considered more environmental aspects in their designs. When DFMA was considered, it was considered in all aspects of design except clarification of tasks step in the design process. This was because clarification of tasks does not require manufacturability knowledge of the design. However, DFE was considered in all aspects in the design process for Class B and all but one for Class A. DFE was not considered in the concept generation for Class A, however, it was highly considered in concept generation for Class B. This suggests that if DFE is considered, it will be reflected in the early stages of design. When the designer initially begins the design process, that this when DFE considerations begin, prior to even developing the design requirements. This theory was supported by the design review data. Class B considered manufacturability more than Class A in all aspects except for design requirements suggesting that there is a tie to DFE and DFMA. Class B considered analogies more than Class A suggesting that DFE has an influence on analogy use. Tying environmental aspects into one's design, increases the need for analogies to make these connections. The use of analogies was also effective in describing the design lesson to the end user. No correlation was found between Class A and Class B effectiveness of design analogies and use due to the teachers not indicating the team that developed their design on the survey. A flaw in the design reviews was that students looked to the teacher for feedback. Looking for feedback may have decreased confidence in presentations, driving designers to leave out their reasoning for choosing design methods and attributes. Reasoning as to why they chose certain materials could have provided more information on whether DFE principles were considered. A statistically significant number of responses attributed the selection of specific design functions and forms to DFE considerations ($P<0.01$) and that DFE caused teams to consider analogies throughout the design process ($p<0.2$). The only other response with any statistical significance indicated that peers are the primary source of influence for manufacturing considerations $p<0.1$).

8 CONCLUSION AND FUTURE WORK

The results of this preliminary research are interesting, but indicate that a better experimental design is necessary. Many of the survey tools did not yield statistically significant results, although it does appear that DFE designers used analogies differently in their design methods as well as the design outcomes. DFE designers considered DFE in the full design process, whereas DFMA was regarded in the later stages. Now that it is known what portion of the design process DFE or DFMA is reflected, our next focus is on how we can capture that and use it to benefit design education. Like the use of DFE and DFMA, we also want to investigate how we can further capture the influence of DFE and DFMA. Class B considered, manufacturability more than Class A in all aspects except for design requirements suggesting that there is a tie to DFE and DFMA. Future work will explore if there is a correlation that ties DFE and DFMA. This may be represented the student's education background, such as major, or even research interests. Students more interested in the materials focus of mechanical engineering may demonstrate a more DFE in their design requirements, were as students focused more on solely manufacturing may not. This can be explored by documenting if the student participates in research or even if they have taken a materials course, or course that teaches sustainable engineering practices. This would demonstrate added influence of DFE or DFMA. Future efforts plan to look at the Product Document Specification (PDS) forms. These sheets were filled out weekly by each team and indicated the products specifications each week. Since the PDS was documented weekly, the changes in the specifications can reflect actual considerations of the cultural influences that were captured from the surveys. The PDS can show if what was implied from the team survey was implemented into the design and design process. It will show how the design requirements changed over the course of the semester, and can even show if there is a correlation between the specifications and lessons taught that week. Influence for DFE and DFMA was shown to came from all parties, supporting the theory that we can capture were influence comes from. However, no correlation was made in what party contributed to what step in the design process. Assessing the PDS forms, may potentially highlight the degree of how many team members influenced DFE or DFMA based on team member responsibilities and objectives.

REFERENCES

Ashley, S. (1995), Cutting costs and time with DFMA. Mechanical Engineering, 117(3), p.74.

Ball, L. J., Ormerod, T. C. and Morley, N. J. (2004), "Spontaneous analogising in engineering design: A comparative analysis of experts and novices", Design Studies, 25(5), pp. 495–508. doi: 10.1016/j.destud.2004.05.004

Boothroyd, G., Dewhurst, P., & Knight, W. (1994), Product Design for Manufacture and Assembly. New York: Marcel Dekker.

Bucciareli, L.L. (2000), *Designing Engineers*, MIT Press.

Christensen, B.T. and Schunn, C.D. (2007), "The relationship of analogical distance to analogical function an preinventive structure: The case of engineering design", *Memory and Cognition*, Vol. 35, No. 1, pp. 29-38.

Chowdary, B. V. and Harris, A. (2009), "Integration of DFMA and DFE for Development of a Product Concept: A Case Study", in *Seventh LACCEI Latin American and Caribbean Conference for Engineering and Technology (LACCEI'2009)* 'Energy and Technology for the Americas: Education, Innovation, Technology and Practice', pp. 1–8.

Constance, J. (1992), "DFMA: learning to design for manufacture and assembly", *Mechanical Engineering-CIME*, 114(5), pp.70-75.

Cross, W., Beitz, W., Feldhusen, J., and Grote, K. H. (2001), "Designerly ways of knowing: design discipline versus design science", *Design Issues*, Vol. 35, No. 1, pp. 49-55.

Ertas, A. and Jones, J.C. (1996), The engineering design process. New York: Wiley.

Fiksel, J. (2009), Design for Environment: A Guide to Sustainable Product Development: A Guide to Sustainable Product Development. McGraw Hill Professional.

Giudice, F., La Rosa, G., & Risitano, A. (2006), Product Design for the Environment: A Life Cycle Approach. CRC press.

Haik, Y., Shahin, T.M. and Sivaloganathan, S. (2010), Engineering design process. Cengage Learning.

Haponava, T. and Al-Jibouri, S. (2010), "Establishing influence of design process performance on end-project goals in construction using process-based model", *Benchmarking: An International Journal*, 17(5), pp.657-676.

Linsey, J. S. and Viswanathan, V. K. (2010), "Innovation Skills for Tomorrow's Sustainable Designers", International Journal of Engineering Education, 26(2), pp. 451–461.

Pahl, G. and Beitz, W. (1996), *Engineering Design: A Systematic Approach*, Springer, Berlin. http://dx.doi.org/10.1007/978-1-4471-3581-4

Purcel, A.T. and Gero, J.S. (1996), "Design and other types of fixation", *Design Studies*, Vol. 17, No. 4, pp. 363-383.

Shrnhue, A.J., Levy, O. and Dvir, D. (1997), "Mapping the dimensions of project success", *Project management journal*, 28(2), pp.5-13.

ACKNOWLEDGMENTS

Thank you to Clemson University, and the students and professors affiliated with CEDAR and the DICE Lab, as well as the professors of the Mechanical Engineering Design Course for making this research possible.