Chaos and Control: How First-Year and Upper-Level Students Experienced Design Differently in a Project-Based Class

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***Abstract*— To give first-year engineering students the chance to learn from upper-level students and to provide upper-level students with leadership experience, we created a class that purposefully mixed these two groups on design teams. The one-semester class was centered on a term-long project where teams of four to five students designed products for elementary-aged children. Each team had a mix of first-year and upper-level students. During the projects, the teams iteratively navigated understanding their users, formulating the problem, deciding what product to design, designing their product, and building a fully operational prototype that their end users could test. In this paper, we compare the main learnings of the first-year and upper-level students to see how they are similar and how they are different.**

We use the final reflections of students as a lens into their learning. The final reflections were structured around a six-slide template wherein students selected an icon, two photos, a quote, a number, and a pivotal moment on successive slides to represent something they learned from the class. Each slide also contained a written description of the "learning" represented on that slide.

Results showed upper-level students and first-year students had different experiences in the class, largely centered around their different conceptions of time. Compared to first-year students, upper-level students were more focused on time management, including the importance of planning and the significant workload that design requires. Keep designs simple so that you can get them done! Seek control to reduce your stress in the messy world of design. First-year students, on the other hand, had a proportionally higher focus on iteration and empathizing with users. Iteratively improve your design so that it better meets user needs! Embrace the chaos of the messy world of design. At the root of these differences appears to be that time had a fundamentally different meaning to first-year students compared to upper-level students; time as an investment in products that better meet users' needs (first-year) versus time as a resource to be managed (upper-level).

Keywords*— *Engineering design; design learning; reflection; assessment; project management, user-centered design; vertically integrated teams; mindsets

I. Introduction: Divergence of Learning Experiences in a Single Design Class

In this Research Full paper, design is framed as being used to address ill-structured, open-ended problems with multiple, conflicting objectives, multiple alternatives, multiple stakeholders, and no one right answer. Accordingly, design classes typically incorporate assignments and projects centered around students applying design approaches, methods, and principles to such open-ended problems. In engineering, these projects frequently are taken on by teams of students, with faculty instructors providing feedback and guidance. Compared to classes more heavily based on math and theory, where closed-ended homework sets and tests are common, the range of experiences of different students in an engineering design class are more varied. Understanding these unique experiences of students is important as these experiences form the basis for learning about design.

In this work, we study the unique experiences of twenty-three students in a human-centered product design class. In the class, a mix of first-year engineering students and upper-level students were grouped into five teams. The one-semester class was centered on a term-long project focused on designing products for elementary-aged children. During the projects, the teams iteratively navigated understanding their users, formulating the problem, deciding what product to design, designing their product, and building a fully operational prototype that their end users could test. The goal of this study is to explore the question: what is the nature of the learnings of first-year students compared to those of upper-level students in an engineering design class?

II. Context: Engineering Design Learning and Reflection

A. Vertically Integrated Design Teams

A study of 23 chemical engineering students on vertically integrated teams focused on using reflective journals to capture how students engage in metacognition and how the journals themselves facilitate the construction of knowledge. While the study was not focused on comparing the experiences of first-years with upper-level students, the social nature of teamwork as a mechanism for more competent students to mentor and guide less competent students was identified from the journals [1]. Another project that combined first-year and upper-level students in chemical engineering reported on the evolving roles of students across all four years, with seniors reporting more about leadership and delegation and lower-level students more on learning ways to contribute [2].

In the EPICS program at Purdue, first-year students join upper-level students on multi-year projects. EPICS at Purdue has experienced and worked to mitigate "specific issues with first-year students" – namely that most are learning to live on their own for the first time and are not used to working on unstructured projects [3]. Mitigation approaches include assigning a mentor to first-year students, enrolling all of them in a cohort-based learning community. and using specific technologies that are quick to learn and therefore allow first-year students to contribute meaningfully. Later work at Purdue showed the importance of the learning community to the first-year students' experience [4].

Started in 2015, the Vertically Integrated Projects (VIP) Program seeks to build from the EPICS model but focus more on using vertically integrated teams to support faculty research [5]. One study on VIP teams at Georgia Tech (n=483) focused on if different years of students provided more help to teammates. Results were not very conclusive, but generally showed more senior students providing more help when focusing only the three years of students for which the program is designed (sophomores, juniors, seniors) [6].

At Rose-Hulman, vertical integration was established between senior and junior students with the intent of enabling the "more senior students to guide and advise their more junior classmates" [7]. As seen with both EPICS and the VIP Program, the theme of using vertical integration as a mentoring role is strong throughout the literature. In the Rose-Hulman case, the two groups were not in the same class or working on the same project; the primary purpose was mentoring. While the methods of this study erred on the casual side, the authors did report both groups of students largely expressing benefits not only on their immediate projects but also more generally with confidence.

B. *Engineering Design Experiences*

Nearly all description of engineering design describe it as a "process." The nature of what is meant by the word ***process***, however, differs between descriptions. Table I highlights how design may be defined as a process differently.

Design as a set of steps or phases of activity are models of the types of "design activities" that occur during a process. Design as mindsets one brings to a problem, a social process, and an emotional journey, on the other hand, are more abstract concepts that provide an arguably richer model of the experiences and attitudes of people who design. The design activities of "steps" and "phases" are done by designers; mindsets, social processes of design, and emotions are of the designers themselves.

TABLE I. MODELS OF DESIGN AS A PROCESS

Design may be…	**for example**
A set of steps	Pahl and Beitz [8]; Dym and Little [9] , Ulrich and Eppinger [10]
Phases of activity	"scoping, generating, evaluating, and realizing ideas" [11]; "inspiration, ideation, and implementation" [12]; converge and diverge [13]; "Hear, Create, Deliver" [14]
Mindsets	Embrace ambiguity, Talk Less and Do More, Be Optimistic and other mindsets from The Little Book of IDEO [15]
A social process	Bucciarelli [16]
An emotional journey	Feelings of fear, happiness, stress, frustration, being overwhelmed, overcoming, worry, etc., can be experienced during a design project.

C. *Reflection as a Mechanism to Observe Design Process Learning*

Experiences of a person and reflection on those experiences forms a basis for learning. Ambrose writes that students learn only when experiences are joined by reflection- "students learn by doing, but only when they have time to reflect on what they are doing" [17]. Schön writes that experiences are necessary but that reflection helps ensure that students do not "have the experience but miss the meaning" [18]. Turns, et al., refer to the importance of making meaning from experiences through reflection in saying that "meaning matters;" they continue that "there are usually multiple ways to interpret or make meaning of experiences, and how we make meaning has consequences" [19]. Collectively, the varied experiences of different students in the same engineering design class combined with the multiple ways to make meaning from those experiences results in design learning that is unique to each student [20].

III. METHODOLOGY

A. *Theoretical Basis for Methods Used*

1) *Epistemological Perspective*

Central to this work is viewing the world in the students' own words. Specifically, we are looking not only at markers of the experiences of students themselves (as represented by the photos, quotes, etc.), but more centrally at the meaning associated with those experiences. It is important to look at meaning-making in the students' own words instead of, for instance, a set of learning objectives written by an instructor, for several reasons. First, it opens up the range of possible meanings that students can make – students have the freedom to make meaning from their experiences however they see fit. Second, word choice matters – e.g., one student referring to learning about time management can be using words related to stress while another uses words related to camaraderie and joy. By focusing on meaning-making and reflection by the learners, we are grounding this work in a constructivist viewpoint.

2) *Research Strategy*

The research strategy is qualitative and may best be characterized as basic interpretive [21]. Students created data characterizing their own experiences; we first coded responses to an a priori coding scheme and then open coded to go deeper into patterns that emerge. The data precedes theory and the analysis involved an iterative process of coding, grouping, recoding, and regrouping. Any theory emerging from this work is only applicable to the specific setting in which it was collected - in this case a specific class at a specific university with a specific group of students. The goal is not to develop a grand unified theory but instead to better understand how different years of a student within this single class make sense of their experiences. We grouped the open codes by characteristics of the learner to see if certain characteristics are more common in certain types of learners.

3) Explanatory Framework

The primary goal of this work is to identify what if any differences there are in the learnings of first-year students versus upper-level students in the same class. Explaining why we see certain differences is not at the core of this work. There are many possible reasons learners from different years could learn different things. The learners could

- be at different developmental stages (e.g., Perry [22])
- have different responsibilities outside of this class
- be motivated differently (e.g., getting through the first term of college versus landing a critical internship or building out a portfolio)
- have different support networks (e.g., first-year students being reliant mostly on each other while upper-level students having developed a deeper network of support).

These reasons are not explored in this work – in no small part due to the limited sample size.

B. Sample

Twenty-three students from an engineering design class (with twenty-four total students) completed a reflective assignment at the end of the term. Eight students (all males) were first-years intending to major in computer science or engineering. Fifteen students (nine of which are male) were upper-level students. Three upper-level students were majoring in architecture and twelve were majoring in a mix of engineering disciplines (most were in computer engineering, systems engineering or electrical engineering). The first-year students were effectively randomly assigned to this class as one of the options for their introduction to engineering class. The upper-level students chose to take this course as an elective.

The class centered on a 13-week project where students designed educational toys for children. As part of the 13-week project, students teams (4-5 students per team) engaged users and stakeholders throughout the project, generate and prototype multiple solutions, and iteratively develop a final working system for playtesting by children. Included in this time was a 3-day design sprint where the teams spent 8 hour/day on project work. At the final playtest, over 100 children interacted with each design. The class focused on designing the function, form, and user experience concurrently throughout a project. Students read most of Norman's *The Design of Everyday Things* alongside the project during the first half of the semester [23]. Each team had a mix of first-year and upper-level students.

C. Assessment Instrument: What to Make of It (W2MoI)

Students prepared a set of presentation slides for What to Make of It that each include a "learning" from the class, a cue for that learning, and a short written description of the learning. Students had to use the following types of cues on different slides: 1) an icon related to their one "big idea", 2) a half-slide picture or drawing, 3) a quote, 4), a whole-slide picture or drawing, 5) a number and 6) a pivotal moment from their project. These six types were selected as they seemed to be a diverse set of easily accessible markers of a student's experience. The markers served as the basis around which students make meaning from their experiences; thus, having a range of different markers types is intended to nudge students into considering a range of experiences. A slide template was given to the students which outlined these cues along with an example W2MoI as a model of general expectations. Students were given roughly one week to complete the W2MoI reflection. We developed a coding scheme in prior work (shown Table II) by coding several responses to identify areas that frequently emerged in the responses *and* by comparing what we found with the conceptions of design outlined in Table I [20].

W2MoI was chosen as the assessment instrument for two conceptual reasons. First, W2MoI is a tool for students to document artifacts from their experience (quotes, numbers, photos, a pivotal moment in class) and connect those markers of their experience to meaning. This focus is desirable as it encourages students to make meaning directly from their own experiences. Further, W2MoI provides a framework for students to synthesize learnings that can be transferred to new situations. A significant design experience in a class can be overwhelming and exhausting - figuring out how to transfer learnings from that experience to other situations is critical. By choosing W2MoI, we are choosing an instrument focused on this transfer. W2MoI was also selected based on its prior use. In a prior study, it showed the ability to extract a wider range of information about student learning than another instrument that was more focused solely on process [20]. This wider range is desirable here as we are interested in more than just those things directly related to a process description of design.

D. Methodology and Analysis

W2MoI responses were de-identified as much as possible and randomly ordered. The coding scheme is outlined in Table I [20]. The coding process focused on the written learnings and associated explanations, not the cues, from W2MoI responses. The coding process was performed by a single rater. The rater first identified segments and then mapped them to a coding scheme. To ensure intra-rater consistency, responses coded earlier in the process were rated a second time later during the coding and discrepancies were identified and reconciled.

TABLE II. PRIMARY CODING SCHEME

Design steps/activities (done by designers)	**More abstract concepts (of the designers themselves)**
○ Overall design process	○ Emotions – design as an emotional journey
○ Empathy / Users / Needs	○ Social process of design -- teamwork
○ Creativity / Ideation / Divergence	○ Mindsets – attitudes brought to design
○ Prototyping	
○ Iteration	
○ Time management of steps/activities	

Segments from student reflections were mapped to the nine codes in Microsoft Excel. We then investigated which codes were more common for first-years and which were more common for upper-level students. Due to the large number of responses regarding the mindset code, we also created a second set of codes around common themes of mindsets. The mindsets were then coded according to these eight mindset codes, which are listed here.

Mindset 1) **Be the user**
fervently focus on empathizing with users' needs

Mindset 2) **Embrace lots of ideas**
including wild and seemingly unreasonable ones

Mindset 3) **Prototype to learn and advance**
akin to the "talk less, do more" mindset from Little Book of IDEO [15]

Mindset 4) **Let it go**
be ready to let go of ideas / pivot to new ones

Mindset 5) **Collaborate to succeed**
centered on the importance of effective teamwork

Mindset 6) **Adapt when, not if, things go wrong**
a broader focus on the need to be adaptable during challenging times, more so than Mindset 4's focus solely on letting go of ideas

Mindset 7) **Be open to learning new skills**
typically this focused on learning new technical skills

Mindset 8) **Keep it simple**
a mindset as old as design itself

Mindsets 6- 8 are not directly linked to any single primary code in Table II. On the other hand, Mindsets 1-5 align with elements of the primary coding scheme– these were instances where a student wrote not only about a topic (that was coded with the scheme in Table II) but did so in a way that generalized their learning to a mindset (so was also coded as a mindset). For example, if a student said "when in doubt, you should build a prototype – that will get the team moving again," that would get coded as Mindset 3 (Prototype to learn and advance) because it is referring to an attitude with which one needs to approach design. Additionally, it would be coded with the Prototyping primary code from Table II due to its reference to prototyping. If a student said "the first round of prototyping really helped our project," then that would also get a primary code of Prototyping but of Mindset due to its lack of focus on a general principle/attitude with which to approach design; it referred to a specific instance in the past but did not generalize to the future. Due to this alignment of several mindset codes with primary codes, any segment coded with Mindset 1-5 or its associated primary code was reviewed to ensure consistency of coding.

IV. Results and Discussion:

A. *Primary Coding Results: Upper-level Students Focus on Time and Workload*

While 53% of upper-level students cited something related to time or time management in W2MoI (see Table III), only 25% of first-year students did. This is the only code that shows a percentage gap of 20+% in favor of upper-level students. Understanding/empathizing with users and iteration, two of the most commonly seen codes, are both areas that first-years outpace upper-level students by over 20%. First-years also are more likely to reflect on the emotional journey of design for a designer. While a test of proportions could be used on each comparison, focusing on such tests is not aligned with this study's objective or sample size. Results in Table III were solely used to direct our attention to review the largest gaps between first-year and upper-level students in more detail.

TABLE III. Primary Coding Results – % of Students

n	First-year 8	Upper-level 15
Overall Design Process	25%	33%
Empathy / users / needs	88%	53%
Creativity / ideation / divergence	38%	40%
Prototyping	50%	40%
Iteration	75%	53%
Time / Time management	25%	53%
Emotional journey	50%	27%
Social process	38%	47%
Mindsets	88%	87%

The representative quotes in Figure 1 paint a picture of upper-level students intensely focused on the quantity of work in a design project and how to manage it. First-year students were less focused on the planning parts of design even when they referred to topics such as iteration and time management.

For example, <u>iteration</u> in design frequently occurs when an initial idea does not work as well as desired. Both first-year and upper-level students commented on this phenomenon, but in different ways. Upper-level students more commonly referred to the need to "be adaptable" as a planning strategy to respond to unexpected challenges, acknowledging that you cannot plan for everything when managing a design project. First-year students, on the other hand, focused on letting go of ideas when they are not working even if you are attached to them without focusing on the time management implications of doing so.

Upper-level students frequently mentioned <u>time management</u> in the context of the need for better planning or the sheer quantity and number of hours necessary to finish the class project. For the two first-year students who cited time, one reflected on how "worth it" the time spent learning new skills was; the other on how a design project is not something you can cram into one night… it is a process that takes time. These two first-year students focused on the value and necessity of *investing* time on a design project, not on how to plan for the magnitude of time required. In contrast, every one of the upper-level students who mentioned time only focused on how much time was required and/or how to better manage a team in the face of such time requirements. For the upper-level students who commented on time, the dominant tone was that one should not invest time into a project but instead reduce time spent as much as possible while managing what remains efficiently.

Not only did first-years (50%) reflect on the <u>emotional journey of design</u> at a higher rate than upper-level students (27%), the type of comments about emotions was very different between the two groups. All four upper-level students referred to emotions associated with the quantity and intensity of the workload. Three directly cited "stress" of working so hard, but things like fun and "happiness" were also cited as emotional responses to the intense work of finishing their projects. Regardless of the nature of their emotional reactions, the trigger for those emotions was the workload. First-year students, on the other hand, have emotional reactions to many things not related to the workload. For example, emotions were triggered by

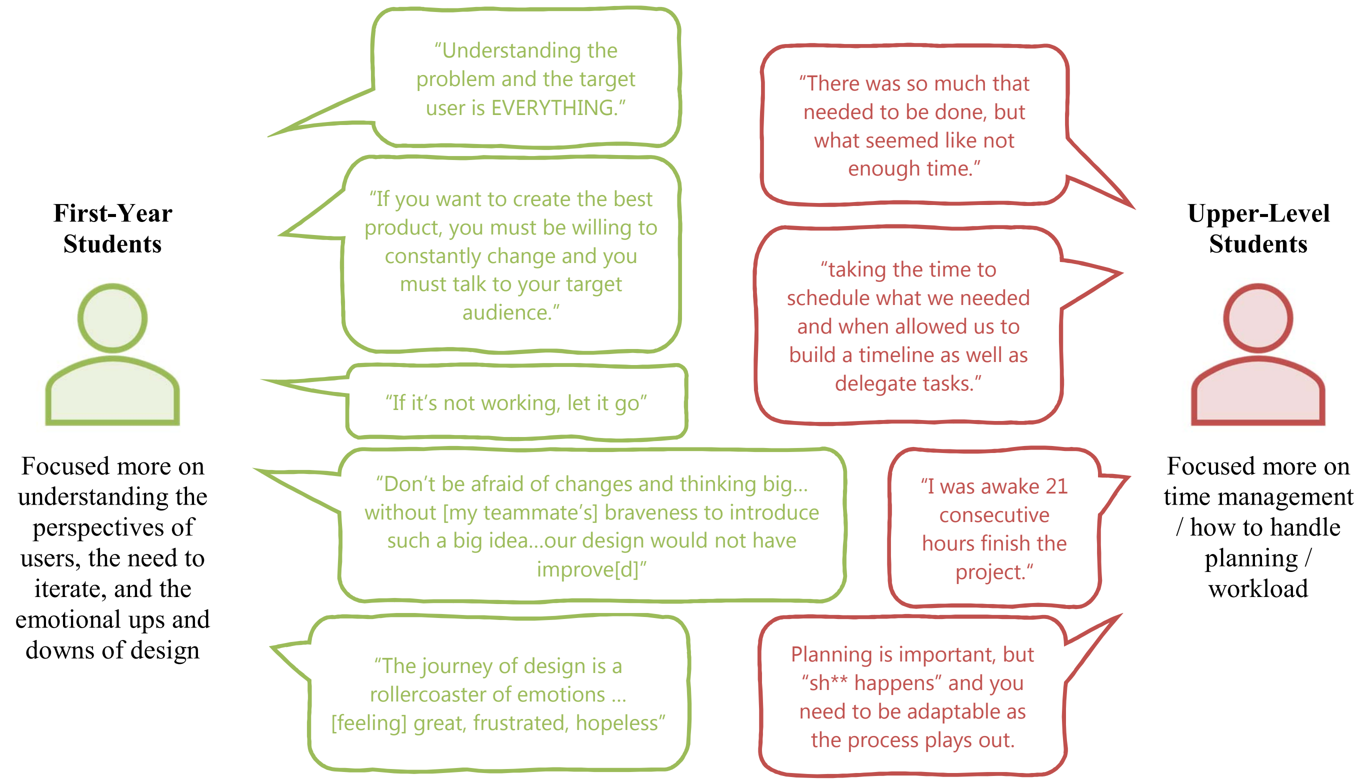

Fig. 1. Representative Quotes

letting go of ideas ("courage" to let go of an idea you are "passionate" about), having teammates not get their parts working ("frustration"), to thinking big ideas (not being "afraid"), and seeing the end product (a "rewarding" feeling). In sum, for the students who spoke to the emotional journey of design, first-year students never cited workload as a trigger while all of the upper-level students did.

Taken together, the clear pattern among upper-level students is a focus on amount of work and how to manage it. For first-year students, the lack of emphasis on workload allowed them to reflect more fully on the design process itself; in particular, first-year students focused on design as a user-centered iterative process where designers experience the emotional ups and downs along with way. For upper-level students referring to time, time should be managed to reduce stress. For first-year students referring to time, time should be invested to learn and create a better design.

B. *Mindset Coding Results: Upper-level Students Focus on Simplicity to Manage Workload*

After the primary coding, a deeper dive into the data further revealed the intensity of the focus on "getting it all done" by upper-level students. Each segment whose primary code was "mindset" was coded again into one of eight mindset codes. These mindset codes emerged from an open reading of the mindset segments. The results are shown in Table IV.

Recall that a mindset is more than just recounting that something was important once on your project. To be coded as a mindset, a student needed to generalize their experience into a principle or attitude that could be used moving forward. A reflection is not necessarily forward looking, but mindsets are.

TABLE IV. MINDSET CODING RESULTS – PERCENTAGE OF STUDENTS

	First-year	Upper-level
n	8	15
Be the user	63%	20%
Embrace lots of idea	13%	27%
Prototype to learn and advance	50%	27%
Let it go	38%	40%
Collaborate to succeed	13%	7%
Adapt when, not if, things go wrong	13%	27%
Be open to learning new skills	13%	7%
Keep it simple	0%	40%

The two biggest trends from mindset coding are that

- upper-level students develop mindsets around <u>keeping designs simple</u> at a higher rate than first-year students
- first-year students develop mindsets around <u>user-centeredness</u> at a higher rate than upper-level students

"Keep it simple" is an age-old mantra of designers. A primary reason to keep things simple is to make sure you can deliver a working system in the time and budget allotted. That is, "keep it simple" is as much a project management principle as it is a design principle. In this way, the mindset "keep it simple" aligns well with the primary coding findings that upper-level students focus more heavily on managing the intense workload in design projects. Keeping a design simple is a way to reduce and manage that workload.

Given that adopting a user-centered mindset in students was a primary aim of the class, it is not surprising to see 63% of the first-year students reflecting that mindset in their W2MoI submissions. Perhaps more surprising is how few upper-level students (20%) included that mindset in their W2MoI submission. While some solace is gained from 53% of upper-level students *talking about* users in design (from the primary coding), that only 20% generalized their reflections into a mindset is low. The data is not definitive on how this could happen, but some clues are given by one of the upper-level students who displayed the Keep It Simple mindset. This student wrote:

> *…one of the most necessary aspects I can take from this classroom is the obstacle in truly obtaining feedback from a user directly using your product. Perhaps that is the burden of being a designer (regardless of how experienced they are) the user will constantly be an unpredictable factor.*

There is a sense in this quote that the user is an "obstacle" unwilling to share their true feedback and a "burden" to the designer. This burden is "unpredictable" – which pushes directly against the desire to control and manage the process as seen in upper-level students. With such a strong focus on managing time wisely, perhaps it should be no surprise that upper-level students were not as likely to leave the class with a user-centered mindset. This quote, however, is from just one upper-level student and does not represent the views expressed by all of the upper-level students about users.

V. Discussion And Implications

The focus of this work is characterizing the meaning making of two different groups, first-year and upper-level students, enrolled in the same project-based engineering design course. Coding responses of twenty-three students showed that a higher proportion of upper-level students focus on time management and the immense workload that can be part of design projects. Their responses show a strong desire to control the workload. First-year students, on the other hand, focused on the design process itself, including the importance of letting go of ideas (even if it creates more work) as part of an overall user-centered mindset. They also embraced the emotional ups and downs of the journey not as stress to be reduced, but as natural parts of the process (while upper-level students' emotional experiences were all triggered by the heavy workload and frequently focused on stress). When first-year students did comment on time, they referred to it more as an investment than as something to be managed and controlled.

The prior literature about vertically-integrated engineering design teams does comment on the differences between first-years and upper-level students. The most related prior work appears to be the 2004 article by Qamar, et al., who found that seniors focused more on the management activity of delegation. While this is distinct from time management, it does show upper-level students took on management roles more so than first-year students.

Most other prior work focused on upper-level students mentoring and providing direct help to first-years – which is not what we found here. Nowhere in our data is there any indication that first-year students needed help finding ways to contribute when compared to the more experience upper-level students on the team. There were no students who reflected on mentoring first-year students.

The most direct application these findings is in the engineering design classroom and relates to how each group views time. While not every first-year student in this study embraced the chaos that users and iteration bring to design and not every upper-level student wanted to design the simplest system to reduce their own stress, this study has shown a cultural difference among these two different groups. Knowing this difference has direct implications on designing learning experiences.

Upper-level students were not as able to focus on the process of design in this study due to their intense focus on workload and time management. An instructor with students showing such tendencies can take many approaches. One approach would be to design a course with less work such that the workload stress does not get in the way of design learning. Another would be to provide more structure to the work so that the management of the workload is more shared by students and instructor. Developing ultra-clear, regular milestones could mitigate the degree to which workload management dominated the minds of students. The class in this study had regular milestones that gave each team flexibility in how they progressed – thereby putting more of the management decisions on the teams themselves. A third way forward would be in the opposite direction; instead of structuring the class more, give students more control not only of how they use their time but also of the level of quality of final products. That is, make a class more fully process-focused. Being more relaxed about the final product quality while maintain a high bar for process could take pressure away from the teams such that time management would not be such a dominant driver of their experience.

Instructors of classes with students showing the tendencies of first-year students in this study, on the other hand, can design classes more akin to the one in this study. Key characteristics of the class include that it included the real-world messiness of design (e.g., more authentic users, more expectations of non-linear iterative design), gave students flexibility in how they met regular milestones, and ended with a fairly high-stakes event where 100+ users came to test functional prototypes designed and built by the students.

VI. Limitations and Future Work

With respect to limitations, the coding was executed by a single rater. The limitations associated with only having one rater were partially mitigated by intra-rater checks throughout the coding process and a significant iteration that included reading and re-reading student responses. Given that this is a cross-sectional study where some of the students self-selected into the class, the generalizability of the results is limited and the connections between student level and the findings cannot be considered causal. Further, the sample of first-year students, while their assignment to this class was effectively random, only consisted of males. Finally, the limited sample size is both a strength in that we were able to analyze their responses in depth, and a limitation due especially to the lack of random selection.

The temptation is to propose reasons to explain the different experiences of first-year and upper-level students. The design of this study, however, cannot do that. There are plenty of possible explanations one can imagine. Future work includes exploring the themes from this study and their possible causes.

VII. Closure

The focus of this work is characterizing the meaning making of two different groups, first-year and upper-level students, enrolled in the same project-based engineering design course. Coding responses of twenty-three students showed that a higher proportion of upper-level students focus on controlling the workload of the design projects through time management and keeping designs simple. First-year students, on the other hand, focused on the design process itself, including the importance of letting go of ideas (even if it creates more work) as part of an overall user-centered mindset. Strikingly, all upper-level students who reported on their emotional experience did so in reference to workload and time management. When first-year students did comment on time, they referred to it more as an investment than as something to be managed and controlled. At the root of these differences appears to be that time had a fundamentally different meaning to first-year students compared to upper-level students; time as an investment in products that better meet users' needs (first-year) versus time as a resource to be managed (upper-level).

Acknowledgment

The author would like to thank the students in the class and the teaching assistants who supported the students throughout the projects.

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