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Design Intentions: Engineering Students Looking Ahead to their Future Design Behavior

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Abstract
In this paper, we present findings of what students declare as their intention to engage in a design behavior after they have participated in a classroom exercise. Specifically, we analyzed data from 73 students from two different classes in a college of engineering in a large public research-intensive university who participated in a classroom activity that took approximately 50 minutes long. After learning about design processes of engineers with various levels of expertise and responding to questions about what they found to be important information, students were asked 'Will Information from this exercise affect how you will do design in the future? How?' Through coding students' responses, we discovered that students are thinking metacognitively about design through articulating plans, efficient use of time, monitoring their steps, and evaluating their design processes. While all students can articulate their design intentions, some students explore a nuanced understanding of their design intentions and subsequent actionable strategies that could impact how they design in the future. This practical classroom activity can be used at the beginning of time-intensive design experiences (such as term-long design projects or capstone design courses) to help students develop a targeted understanding of important aspects of the design processes and set intentions for how they will engage in their design projects.

Introduction

As we critically consider what we mean to accomplish in design teaching and learning, we can distinguish among the exposure to design practices and processes, intention to engage in design practices and processes in specific ways, and the subsequent design behavior that changes the practice and process.

The goal of this paper is to understand engineering student design intent. We build on a long-term research program in which we have used research results from studies of design expertise to teach about the design process. Specifically, we leverage timeline representations of individuals engaging in a design task to convey design behaviors of designers with various levels of expertise. These representations have been shown to be very effective in promoting student understanding of important aspects of the design process (e.g., the need to spend time problem scoping before engaging in modeling; the need to engage in a broad set of design activities; the need to iterate among design activities). However, recognizing specific elements of design, while important, is not sufficient when it comes to engaging in specific design behaviors. Intent can be seen as an intermediate step between an individual being aware of an action to take, and actually taking that action. We ask: Do students articulate and understand their intentions for changing how they engage with design and if so, how?

In this paper, we present findings of what students declare as their intention to engage in a design behavior after they have participated in a classroom exercise. Articulating design intentions sets the stage for developing goals and behaviors that would result in changes and improvements to one's quality and overall design process in the future.

Background

Key characteristics of successful learning can be explained by drawing on theories and models of self-regulated learning. These theories and models of self-regulated learning acknowledge cognitive, social, cultural, and contextual factors that influence learning. Having students set goals enables them to develop strategies so that they start becoming self-regulated learners that are active participants in their own learning. In this section, we discuss the affordances related to goals. Having students set goals for their learning predisposes them to self-regulating practices. In addition, self-assessment activities that include planning more effective means to achieve goals is at the heart of self-regulated learning. Drawing from a social cognitive perspective, we then present the processes of self-regulated learning and related metacognitive skills. Finally, we discuss self-regulated processes and strategies in relation to sources of motivation.

Knowing about specific elements of design, while important, is not sufficient when it comes to engaging in specific design behaviors. Drawing from Gollwitzer's [1] notion of intentions, having students articulate their design intentions entails developing their self-regulatory skills that promote the initiation of goal-directed behaviors and ultimately taking purposeful action. Consequently, intentional and goal-directed processes are constituents of self-regulated learning [2]. Hadwin et al. [2] explain that goals enable students to commit to a particular standard or outcome that can subsequently be used for self-evaluation. On this account, goals are central for students to develop regulatory skills and achieve future success because they contextualize strategies, and they provide students with standards that they can use to monitor and evaluate their learning. For educators, gaining insights into students' intentional and goal-directed processes makes visible students' orientations, motivation, and intent because they make their understanding related to a task explicit and show how they are translating their tasks into goals [2].

From a social cognitive viewpoint [3], self-regulation refers to learning processes that include strategies for achieving goals on the basis of self-efficacy perceptions. This viewpoint accounts for self-regulated learning strategies, self-efficacy, and commitment to goals. Thus, implying that students are metacognitively, motivationally, and behaviorally engaged in their own learning process. When students are metacognitive, they engage in decision-making processes in which they are responsible for selecting and using various forms of knowledge [3]. As a self-regulated learning strategy, self-efficacy perceptions refer to students' capabilities to organize and implement actions to attain goals. Properties of the task at hand and the conditions, such as the use of time, impact students' ways of approaching design and its outcome. For example, some students make connections to how they engage in the design process and their intended outcomes that would improve their approach to design. While in other cases, students signify design activities that could support the success of their design process. Thus, students' intentions range from choices to future engagements. To support this view, Zimmerman [4] contends that students' perceptions of their self-efficacy are predictive of diverse motivational outcomes that stem from students' choices related to activities, effort, and persistence. Motivational feelings and beliefs raise students' awareness to their learning processes and outcomes. They increase students' choice of a task because of their commitment and their efforts to productively engage in their task. They also increase students' persistence on a task. Research on students' self-efficacy shows that students with high efficacy tend to monitor and adapt their performance more efficiently than students with lower levels of efficacy [4], which in turn influences their goals and outcomes.

In educational psychology, theories of self-regulated learning describe several self-regulatory strategies that relate to metacognitive skills. Schraw and Moshman [5] highlight three essential metacognitive skills that regulate one's thinking and learning: planning for approaches, monitoring one's progress, and evaluating one's own knowledge and skills relative to a goal.

- Planning entails setting goals, selecting strategies, and assigning resources that influence performance. Pintrich [6] adds that planning activates perceptions and knowledge related to the task and context as well as the self.
- Monitoring, like self-observation, refers to one's cognitive tracking of personal functioning and task or context. Such processes represent a metacognitive explanation of the self and task or context [6] that are based on a standard or outcome that is determined by the student. These standards or outcomes in learning environments are akin to learning objectives. Students' knowledge can also serve as a standard because students may draw from prior experiences and expectations about standards and qualities of future performance.
- Evaluating, as a form of self-judgement, refers to comparisons of self-observed performances against some standard, such as one's prior performance or an absolute standard of performance.

Developing students' self-regulatory skills entails observation, emulation, self-control, and self-regulation. Kitsantas and Kavussanu [7] describe observation as observing expert practices. In exposing students to expert practices repeatedly, they begin to learn and discern key expert strategies and ways of doing relative to disciplinary practice. Students then begin to emulate those observed behaviors with support or guidance. As students begin to learn these practices, they begin to practice these skills or strategies focusing on the processes rather than the outcomes. As a result, students are oriented to process goals or what Gollwitzer [1] terms 'implementation intentions. Implementation intentions commit students to executing an intended goal-directed behavior with an anticipated situational context [1]. Gollwitzer [1] explains that the purpose of an implementation intention is to establish specific plans that will facilitate the initiation and efficient execution of a goal-directed activity. Finally, students begin to self-regulate when they merge their process goals with outcome goals or what Gollwitzer [1] terms 'goal intentions', which entail end states. At this phase, students can self-monitor and self-evaluate outcomes and adapt their strategies to fit the expectations of the context.

Given our interest in engineering student perspectives for understanding what they take away from an in-class activity related to design practices and processes, as well as what they intend doing in the future when they engage in design practices and processes. It is useful to take a sociocognitive perspective to explain how students use their design processes when learning about design. Zimmerman [4] outlines several sources of motivation when we consider students' diverse motivational outcomes in relation to self-regulated learning.

Zimmerman [4] presents these sources of motivation in a cyclical phase model of self-regulated learning. In the forethought phase, approaches to an activity are established in task analysis and self-motivation beliefs. Having students set goals predisposes them to self-regulating practices where they decide on the intended outcomes of a task. Another aspect of task analysis is strategic planning. Students set goals and select or create methods that are appropriate for the task and setting. In this phase, students' self-efficacy influences goal setting and choice of strategies to guide their thinking and performance as well as control affect. Outcome expectancies also influence goal setting and strategic planning. These refer to students' beliefs about achieving a solution or outcome and are similar to notions such as 'utility values', which refer to how a task may fit into a student's future plans; and future time perspectives. Task interest and value entails valuing a task for its properties rather than for its instrumental qualities. In this aspect, students interest influences student task choice and future engagement in the task. Finally, goal orientation refers to measures that facilitate the development of students' abilities.

In the performance phase, students engage in processes that influence their attention and effort. In this phase, self-control strategies enable students to focus on a task and their efforts to optimize a solution or outcome. Aspects related to self-control strategies include: Attention focusing which enables students to use a variety of techniques to improve their attentional control. Task strategies enable students to select essential parts of a task and reorganize them in a meaningful manner. Another aspect is self-observation where students track specific aspects of their performance, the conditions that surround it, and the effects that it produces [8].

In the self-reflection phase, students engage in self-judgement and evaluation. Self-Judgement entails self-evaluating a performance or outcome and attributing causal significance to the outcomes. Self-evaluation entails making comparisons from self-monitored outcomes with a standard or goal. Self-evaluative judgements are linked to causal attributions about the results of solution efforts, such as failures due to ability or to insufficient effort. Attributions depend on student's prior motivational beliefs, such as perceptions of self-efficacy or environmental conditions that affect outcome expectations [9]. In addition, self-reactions to efforts influence forethought processes regarding further solution efforts. As a motivational belief, self-reactions form the basis for affording student's greater agency in continuing their cyclical self-regulatory efforts and eventually reaching a solution. Self-satisfaction refers to students' perceptions of satisfaction or dissatisfaction and associated affect regarding their performance or outcome. Finally, adaptive inferences refer to conclusions students make about how they need to alter their approaches during subsequent efforts to reach a solution or outcome. Adaptive inferences direct students to new and potentially productive solution efforts [10].

We have discussed the notion of intention and how it relates to self-regulation as well as self-regulated learning strategies, self-efficacy, and commitment to goals. We then discussed how self-regulatory strategies relate to the three essential metacognitive skills. Finally, we provided an account of developing students' self-regulatory skills and how sources of motivation relate to Zimmerman's [4] cyclical phase model of self-regulated learning. In this paper, we will draw on these theories and models to explain how students use their design processes and establish ideas to further engage their own perceptions when learning about design.

Methods

In this paper, we report on what students found most beneficial to their learning through an in-class lecture and activity of a descriptive design model. Knowing what students found most important and further how they might use what they found most important in the future, we ask: Do students articulate and understand their intentions for changing how they engage with design and if so, how? (See appendix for full worksheet.)

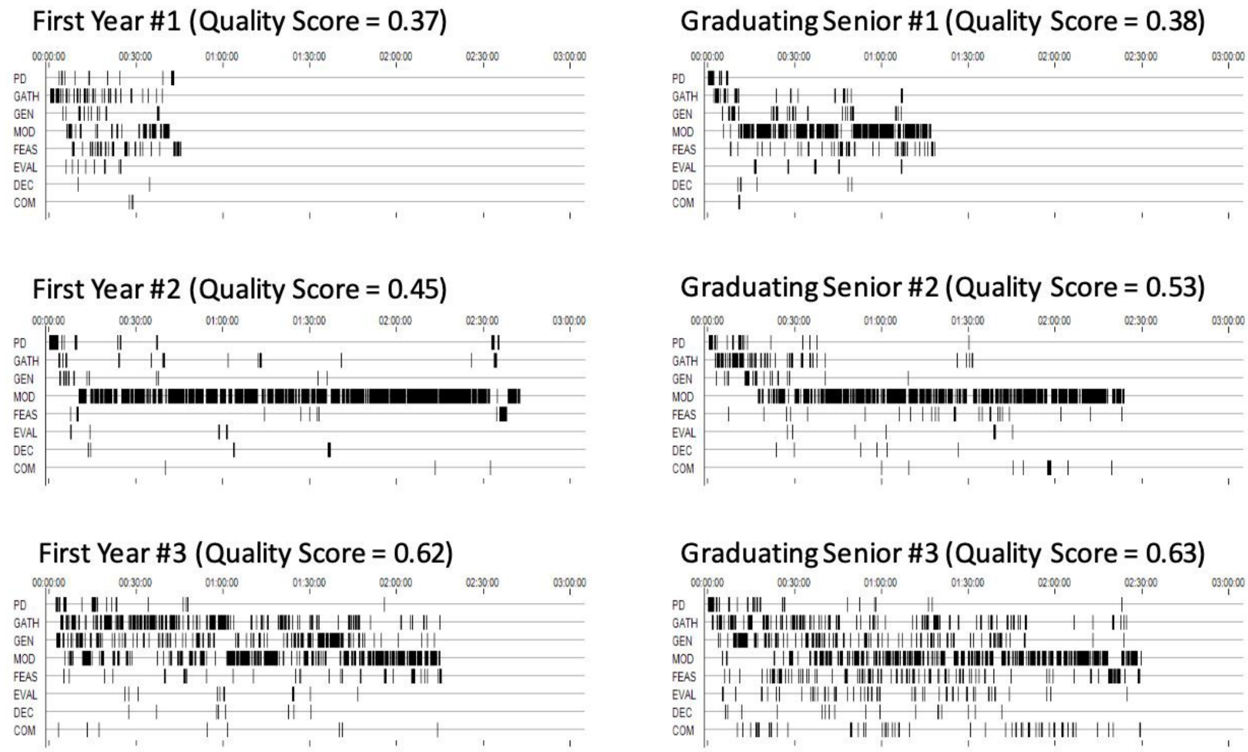
Teaching Engineering Design: An In-Class Activity

In the Winter of 2017, 78 students across two undergraduate engineering classes (50 in a Civil Engineering class, 28 in a Human Centered Design & Engineering class) at a university in the Pacific Northwest participated in an in-class activity for which worksheet data was collected. Students were given the option throughout the worksheet to opt out of the study if desired. During this in-class session students engaged in a two-part worksheet activity process and an embedded lecture.

This in-class activity started with a lecture introducing students to a descriptive design model and design process timelines. Design process timelines are graphical representations that display how an individual allocates time across a set of design activities as they engage in a design process. These representations have been shown to be very effective in promoting student awareness of important aspects of the design process (e.g., the need to spend time problem scoping before engaging in modeling; the need to engage in a broad set of design activities; the need to iterate among design activities) [11]. In Figure 1, the timelines represent typical low-performing, average-performing, and high-performing first year and graduating senior engineering students.

Students were then tasked to individually observe a set of design timelines (see Figure 1 Timelines) and answer the following prompts:

1. What similarities and differences do you see between the first year and the graduating senior engineering students?
2. Do these similarities or differences also involve the quality score? How so?



PD: Problem Definition	MOD: Modeling	DEC: Decision
GATH: Gathering Information	FEAS: Feasibility Analysis	COM: Communication
GEN: Generating Ideas	EVAL: Evaluation	

FIGURE 1. Timelines

In small groups of 3 or 4, students discussed themes they had observed and they were provided an opportunity to note anything they wanted to add from this small group discussion. Finally, the themes students identified when observing the timelines were discussed in a whole-class discussion. From this discussion students were again able to add additional information to their worksheet.

Next, a lecture around the descriptive models was delivered to help facilitate an understanding of how the design process is broken down. Students were given an opportunity to see design in a descriptive model such as a timeline. The timelines represent different patterns that indicate time spent in different design activities and number of transitions among design activities, thus characterizing different levels of expertise. Again, students could add to their worksheet.

Finally, students were asked to answer three questions. These questions would allow students to articulate the most salient points as well as articulate if this activity assisted in their understanding of design and how they might design in the future. Students engaged with a set of three questions that asked students to identify the following:

1. What are the most important things you learned today? Why?
2. Reflect on how you have been done design in the past. Does that differ from the design processes you just learned about in this exercise? How?

3. Will information from this exercise affect how you will do design in the future? How?

Data Sources and Analysis

The data analyzed comes from an in-class worksheet and responses to questions were collected from undergraduate students across two engineering disciplines. A researcher transcribed the 78 worksheets capturing all written responses as well as documenting any images, scribbles or pictures included on the worksheet. A second researcher checked the quality of the transcriptions with the original worksheets and noted any discrepancies. Data analyzed included the following two questions: 'What are the most important things you learned today? Why?' (question 1) and 'Will information from this exercise affect how you will do design in the future? How?' (question 3)

The transcripts were analyzed using Excel with a focus on coding the written data (not focusing on the occasionally occurring sketches). Student worksheets that were left completely blank or opting out of answering any question were also omitted from the analysis, resulting in a total of 73 responses. Student responses for each of the questions were used as the unit of analysis. In question 1, there were a total of 167 codes that were assigned to the answers, and in question 3 there were a total of 194 codes that were assigned to the answers.

Using an inductive approach, two researchers first pre-coded the responses [12] individually and highlighted words and phrases that emerged. The responses were then open coded [13] and in the second cycle of coding, we used focused coding [14] to develop themes [15] and categories from the most frequent occurring open codes. The responses were then coded axially [13] to identify properties of the categories. Finally, for the design codes, the emergent themes were compared to the developed codes from a collective synthesis of several codebooks from previous similar design activity studies [16] [17] and used for this analysis. Several passes were conducted to develop familiarity with the code book and consensus and discussion sessions were held after every coding session. Minor refinements were made to the design code definitions (see Table 1 Design Codes).

TABLE 1 Design Codes

Codes	Sub-Codes	Definition	**Example 1 (2a):** What are the most important things you learned today? Why?	**Example 2(2c):** Will information from this exercise affect how you will do design in the future? How?
Problem Scoping/Problem Framing [PS]	Problem definition is important Problem scoping is important Problem definition early is important Problem scoping early is important Returning to problem definition throughout the process is important Project Start-up	Problem definition or problem scoping is reported as important for high-quality designs. Some insights indicate starting with early stages of design (PD, GEN, GATH) or returning to beginning stages which are recorded as a form of Problem Scoping/Problem Framing.	"I learned that spending more time before planning (i.e. gathering info, understanding the problem, and generating ideas leads to a better product..." - JMIVT	Absolutely! Now I realize the significance of problem defining and project manifestation - 16JVR
Gathering Information [GATH]	Gathering information is important Gathering information early is important Gathering information throughout is important Covering more categories of information is important Doing Research throughout is important	Gathering information is mentioned as an important step within the design process. Nuances to these insights include gathering information early, gathering information through-out, acquisition of more information for a design solution, and finally doing "research" as a form of gathering information.	"Collecting information throughout the experiment is important for overall quality" - GVW6T	Yes I learned to stop modeling so much and work on gathering info and problem definition - LHGRE
Modeling [MOD]	Modeling is important Don't get stuck in modeling	Modeling or not getting stuck in modeling for a higher quality design were mentioned as an important insight.	"Don't get bogged down in modeling - 'lift head from paper'" - 3CDIU	May be beneficial to force myself to not start modeling until further into the project - 4XPTI
Project Wrap-Up [PW]	Project wrap-up is important	Mentions of project wrap up or parts of the design process post modeling (FEAS, EVAL, DEC, COM) as important. These insights may also include realizations of end-stage design activities as a contributor to high-quality design.	"Communication and Decision are great to make better design" - LHGRE	This information will give me a reference on what sort of aspects I should consider while designing. Also, it helps me remember to invest more time into steps after modeling instead of finishing early -6E9BL
Time [TIME]	Spending more time on the design is important	Overall time spent is mentioned as an important factor for high-quality designs. Rather than concentrating on how time is used this code relates to an overall and holistic understanding of time as a factor in the design process.	"It is important to spend enough time on designing to create high quality work." - YJUX2	Yes, quality=more time spent- LS2EJ
Breadth [BREADTH]	Breadth is important	The breadth and the variance in the range of design activities as they relate to time are mentioned as an important insight. Breadth is often talked about in different ways including the spread, variation, scattered time, scattered activities/phases. Any mentions on variations of sounds, distribution, and efficiency with design activities qualify as breadth.	"High-quality designs are reached by spending lots of time doing all different types of activities." - 2DUTN	I will make sure that I am not too focused on one type of activity - YJUX2
Iteration/Transitions /Cycling/Going Back [ITR]	Iteration/ Transitioning is important	Iterations, transitions, cycling, or going back to specific design activities was articulated as a significant insight.	"Importance of going back & forth different phases in design process to deliver high-quality work." - 50JV6	Yes, I will definitely try to constantly iterate over past stages to improve my designs/research. - L95UM
Design Shape [SHAPE]	Design process has a shape	The design timelines are compared to shape and often described as cascading, non-linear, and or complex. Mentions of the Ideal Project Envelope is an instantiation of design shape.	"<--think of that parallelogram envelope "IOF9Q "Cascading shape..." - KEW9Q	...Use design envelope strategy for distribution of tasks - CKTV7
Design is a process (META)	Understanding design as a process overall is important	Insights relating to some better understanding of design as a complex, non-linear, or efficient process.	"The design process works; it helps you consider all sides to your problem." - 3JHZV	I believe this exercise will linger and make me think about how much time I am spending on the design process and what elements/stages of the design process, in particular I am working on. - Y1HWN

We took the same inductive approach and coding procedures used for the design codes when coding student responses for metacognitive instances. After iteratively re-coding and discussing student responses for metacognitive instances, we opted to only code for the codes presented in Table 2. These codes were derived from theories on self-regulated learning and metacognition [18];[5];[19]; [20];[6];[21];[22]. From the discussions, we reached coding saturation based on specificity for the following regulatory metacognitive codes:

TABLE 2 Metacognition Codes

Code	**Description**	**Example**
Planning	Planning and setting goals as well as activating perceptions and knowledge of the task and context and the self in relation to the task.	'Continually gathering information, analyzing, generating ideas, communication and making decisions' - TI0O5 '(cascade shape drawn) <-- Use design envelope strategy for distribution of tasks' - CKTV7
Monitoring	Monitoring one's performance selectively for signs of progress. Self-monitoring, like self-observation, refers to one's cognitive tracking of personal functioning.	'I'll be more active checking my designs and trying to bring in new ideas, rather than sit in a puddle with just a few ideas' - 5F8HO.
Evaluation	Self-evaluation, which is one form of self-judgement, refers to comparisons of self-observed performances against some standard, such as one's prior performance, senior/expert design performance, or an absolute standard of performance.	'I will try to amend the differences between my design style and the high performance designs' - GANU7

All coding cycles were reviewed by both the two researchers and discussed with the lead research expert.

Inter-rater reliability

The two researchers after each discussion session reached consensus and calculated the intercoder agreement [23]. The strength of agreement [24] was used to determine the validity of each pass. The final inter-rater reliability of the design codes was computed using a Pooled Cohen's Kappa. For the first question, we achieved 92% level of agreement which was "Almost Perfect". For the third question, we achieved 86% level of agreement which was "Almost Perfect". The final inter-rater reliability using the metacognition codebook for the third question was 76%, a "Substantial" level of agreement.

Results

We present findings from across the full dataset where we first show what students took away from the in-class activity. Based on the design codebook in Table 1, the coded student responses to question 1, "What are the most important things you learned today? Why?" are presented in Figure 2. Figure 2 shows the overall design code percentages across both engineering classes of student responses to question 1. Next, we show what plans, goals and strategies students reported in response to question 3, “Will information from this exercise affect how you will do design in the future? How?” Figure 3 shows the overall design code percentages across both engineering classes of student responses to question 3. We then present the most persistent design codes occurring in both question 1 and question 3 with selected representative student quotes. These are presented in Table 3 and show how persistent design codes were manifested in the student responses.

Based on the metacognitive codes in Table 2, we look at the overall percentages of coded student responses to question 3, which are presented in Figure 4. Finally, we present pairings that occurred frequently in the student responses, highlighting what students report on based on the in-class activity and other thoughts that were characterized as the three metacognitive skills from both the design and metacognitive codes.

Design Takeaways

In developing students’ understanding of design, doing design and their competencies, students could talk about their experiences in relation to newly acquired information and practices as well as its relevance. This enables students to critically evaluate what they already know and what they need to develop. In doing so, we may gain insights related to what motivates them, what they takeaway, and what they value when exploring the design process. From the in-class activity, students were asked: ‘What are the most important things you learned today? Why?’ In Figure 2, we show the total percentage - that is, coded responses from the two undergraduate engineering classes combined - per code used in the student responses.

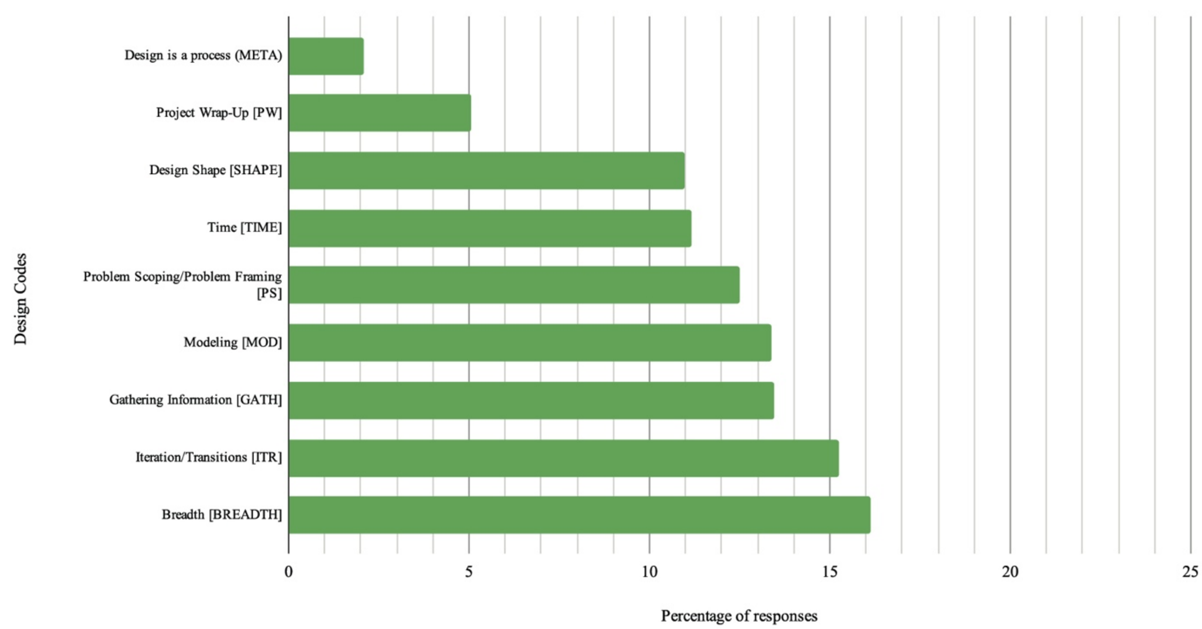


FIGURE 2. Design Codes for Question 1: “What are the most important things you learned today? Why? Percentage of student responses (n =73)

Figure 2 shows the overall percentages of the design codes used to code student responses to question 1, “What are the most important things you learned today? Why?” Below we describe example responses represented in the figure.

Breadth and Iteration/Transitions: Across both undergraduate engineering classes, the design activities related to breadth and iteration/transitions were frequently mentioned as the most important thing students learned from the activity, accounting for 16% and 15% respectively from total percent of student responses. For example, a representative student response coded as breadth and iteration/transitions is illustrated in the following quote:

“I learned that it's important to make sure to not get stuck on one aspect of a design process. Instead we should iterate between all aspects” (Student 21, 322B).

The timeline representations show that the low-performing and average-performing first year and graduating senior engineering students can tend to fixate on design aspects, such as modeling. This in-depth approach to design illustrates how novices can engage in design. For the high-performing first year and graduating senior engineering students, students noticed the importance of breadth in design. This suggests that students are developing an understanding of the importance of breadth in the use of a design activity that is associated with how experts would engage in the design process.

Gathering Information, Modeling, Problem Scoping/Problem Framing: Other design activities such as gathering Information, modeling and problem scoping/problem framing respectively accounted for about 13% for each code. For example, the following student quote encompasses modeling, problem scoping/problem framing, iteration/transitions, and gathering information:

“ideal ways to sequence the design process. I tend to enjoy modeling more than the other tasks but now I see that it is more important to scope the project before jumping into the model; the more transitioning between tasks, the better the quality, this goes to show that gathering information and other tasks should continually happen and that checking/rechecking work is crucial!” (Student 64, CE17)

Time: In relation to these design aspects, students reported that time (11% of student responses) was another important factor that they learned from the timeline representations. Students emphasized distributing their time across design activities, thus ‘spending time in all areas’, not getting ‘stuck in a rut’ or ‘not struggle in only one part for a long time.’ Emphasis on breadth, iteration/transitions and the distribution of time across design activities shows that students are developing “implementation intentions” [1]. Implementation intentions commit an individual to executing an intended goal-directed behavior with an anticipated situational context [1]. As a result, students are articulating newly learned strategies and learning goals in relation to the produced effects of being stuck on one aspect and not distributing time across design activities.

As a form of feedback, the timeline representations expose students to the different approaches that novices and experts use during the design process, thus placing emphasis on breadth over depth. Having students reflect on the most important things they learned from the in-class activity enables them to assess their own strengths and weaknesses in the design process as well as critically explore their approaches and improve on their performances by modifying their design process in more expert ways. At the same time, having students articulate what they learned in relation to the timeline representations enables them to become aware of the naming of design activities and practice design talk, thus gradually shifting their understanding of the design process in more nuanced ways that could potentially go beyond their immediate experience of the in-class activity.

Adjusting strategies for future design

Critically understanding students' individual experience with design and their intentions for future work enables students to explore their approaches in doing design in relation to more expert ways of doing design. While this is important, it is not sufficient when it comes to engaging in specific design behaviors. Intent is seen as an intermediate step between an individual being aware of an action to take, and actually taking that action. In question 3, students were asked: 'Will information from this exercise affect how you will do design in the future? How?' This question is framed so that it primes students to articulate their future design intentions. Figure 3 shows the total percentage - that is, coded responses from the two undergraduate engineering classes combined - per design code used in the student responses.

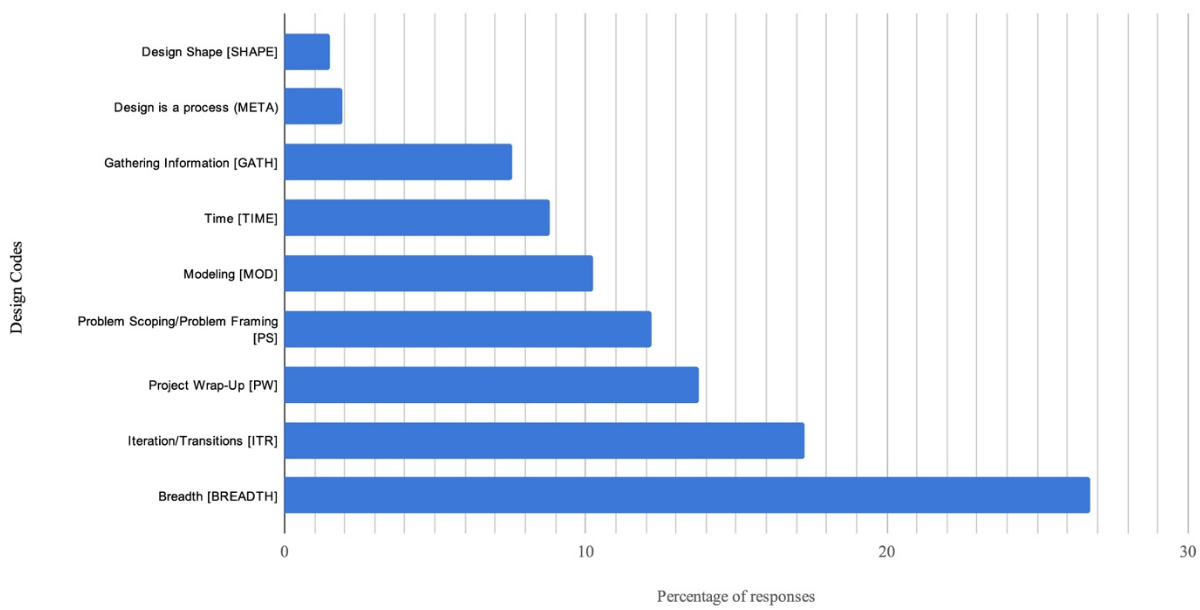


FIGURE 3. Design Code for Question 3: "Will information from this exercise affect how you will do design in the future? How? Percentage of student responses (n =73)

Figure 3 shows the overall percentages of the design codes used to code student responses to question 3, "Will information from this exercise affect how you will do design in the future? How?" Below we describe example responses represented in the figure.

Breadth: Across both undergraduate engineering classes, 27% of the student responses emphasized breadth when doing design in the future. Breadth was predominantly characterized as 'not getting stuck in any single process of the design' or as one student wrote, *"If I start focusing too much on one aspect of design, I will remind myself to shift gears and reconsider my approach"* (Student 15, 322B).

By evaluating their personal outcomes in doing design, student responses were coupled with adaptive inferences. For example, students emphasized the 'importance of doing multiple design steps throughout the process', 'being more diverse with the design steps', 'move to different steps flexibly', and 'think broader' when they find themselves "focusing too much on one aspect of design" or being "stuck in some mono-tonic phase." Other students emphasized breadth in relation to time where they would 'spread...time out more', 'break up the time spent modeling', and be aware of 'how much time to spend on different aspects of design.'

Previous research results from studies of design expertise used to teach about the design process show that a good design process has a "cascade pattern" [25]. In one study, researchers [16] found that this notion of a "cascade pattern" in the design process has a shape and was articulated by a student as the "Ideal Project Envelope." This finding was presented to students during the in-class activity. As a result, two students highlighted the design envelope as a strategy for needing to engage in a broad set of design activities as illustrated in the following quote,

"Use design envelope strategy for distribution of tasks" (Student 30, CE17). This strategy was also coupled with time:
"high quality --> (up arrow) more time (project envelope) <-- spend time like this" (Student 52, CE17).

From these adaptive inferences, students articulate strategies for altering their approach to design in the future. In doing so, student responses contain attributes of dissatisfactory outcomes to the way they do design and promising contingencies in doing design for their future selves.

Iteration/Transitions: Another design activity that students perceived as valuable for the design process is iterating or transitioning between different stages of design (17% of student responses). From the student responses, iterating or transitioning was characterized as 'going back to the different stages of design.' The perceived value of this design activity is to improve the quality of students' designs, as illustrated in the following quote:

"In the future design projects, I definitely will go back to previous phases even though I'm done w/ [e.g.] user research. By going back, I can improve & refine my previous outcome from each phases, which will eventually help me generate high quality work." (Student 6, 322B)

This finding is consistent with previous research findings on how iterative design behavior leads to 'high quality work' [16]. In addition to producing 'high quality work', some students reported that iterating or transitioning between different stages of design will enable them to optimize their solution efforts. For example, one student wrote:

"I will take time to go back and see if my project has satisfied my original need" (Student 49, CE17).

Viewed as a design strategy, iterating and transitioning between different stages of design is perceived as a means to self-control. In self-regulated learning theory, Zimmerman and Campillo [21] view self-control as a process that enables students to optimize their performance. Accordingly, self-control processes entail self-instruction (descriptions on how to execute a task), imagery, attention focusing, and task strategies [26]. Based on a "self-criteria" [9], students can track their progress and 'reconsider their approaches' to achieve self-satisfaction while pursuing this course of action. According to Bandura [9], self-criteria is a form of self-evaluation that refers to comparing self-monitored outcomes with a standard or goal. In ill-defined problem solving contexts, oftentimes one compares a current performance with previous performances. As a result, these self-comparisons involve changes in functioning thus highlighting progress in learning, which is purported to improve with repeated practice. Research on self-regulated learning shows that students' use of strategies depends on students tracking or monitoring the effectiveness of a selected strategy and attributing academic outcomes to it [10]. Zimmerman and Campillo [27] view this as a behavioral category of self-regulation where strategy use is considered an important self-reaction. Self-reactions refer to problem solution efforts that influence forethought processes regarding further solution efforts [27]. Consequently, these adaptive inferences direct students to potentially better solution efforts when they select a more effective strategy [10].

Project Wrap-Up: Students from both the undergraduate engineering classes perceived project wrap-up as an important design activity that will affect how they will do design in the future (14% of student responses). This project realization stage incorporates decision and communication activities and was characterized by students as the 'post-modeling' phase as evidenced in the following quote,

"This information will give me a reference on what sort of aspects I should consider while designing. Also, it helps me remember to invest more time into steps after modeling instead of finishing early." (Student 58, CE17)

The project realization activities were also associated with time investments where students intend to modify their previous approaches to design. As previously discussed under Breadth, student responses include adaptive inferences. One notable adaptive inference present in student responses is the importance of communication, as illustrated in the following quote:

"Yes. Going to try and focus on things I know I struggle with like communication, defining the problem, etc." (Student 19, 322B)

This suggests that students are self-evaluating their approaches to design and making causal attributions about particular abilities they deem limiting. While research on self-regulated learning shows that such attribution judgements may be discouraging for students as they react negatively to outcomes [28], the student responses show intent in overcoming limiting abilities by explicitly stating plans and strategies. These plans and strategies are framed as self-criteria's such as

"Yes I will spend more time gathering information and ideas and not be afraid to go back to these steps. Also spend more time in the other fields like feasibility, analysis, decision" (Student 57, CE17)

"I will make sure to consciously go back and frame the problem and communicate more" (Student, 3, 322B)

While implementation intentions [1] involve planning and setting goals, they do not guarantee that students will achieve their goals, but it does suggest that students are committed to realizing their plans when they do design in the future.

Persistent Design Activities

Some students carried their design takeaways through both questions (see Table 1). As students begin to form implementation intentions, Gollwitzer [1] explains that such strategies promote the initiation of goal-directed behaviors. Goal attainment is more likely to occur when students' design intentions are framed as specific, learning goals [29].

If we consider Student 15's design takeaways, breadth and iteration/transitions are tied to quality. When students are asked how the activity will affect how they do design in the future, the prompt explicitly primes students to engage in goal-directed behaviors. Thus, the first question links students' perceptions to new information and the third question enables students to assess their important takeaways in service of their design intentions. For Student 15, achieving 'quality work' entails making plans that are linked to specific situational contexts. This is articulated in the third question where Student 15 establishes a connection to a situational condition, "[i]f I start focusing too much on one aspect of design" and then commits to an intended-goal directed behavior, "I will remind myself to shift gears and reconsider my approach." Gollwitzer [1] explains that the purpose of an implementation intention is to establish specific plans that will facilitate the initiation and efficient execution of a goal-directed activity. Consequently, an implementation intention is formed conjointly or subsequently with a goal intention.

Attending to the role of time in design and the framing of Student 23's response to what they took away from the in-class activity, we see that their prior opinion related to time contrasts with what was presented and represented in the in-class activity and design timelines. Since the timeline representations are based on research related to design expertise, students are presented with empirical evidence that demonstrates not only differences in how novices and experts engage in the design process but also how a design-related behavior, such as time, has affordances for achieving 'quality work'. In such instances, Gollwitzer [1] states that the formation of implementation intentions may help redefine a situational condition and an intended-goal directed behavior. While Student 23 already held the opinion "that more time spent doesn't always mean higher quality work", evidence from the design timelines dispelled this standpoint, "in this example that didn't seem to be the case." This perception is carried through to the third question. When a goal intention, characterized as achieving a certain outcome, is supplemented with an implementation intention, Gollwitzer [1] contends that there is an increased likelihood that it will be accomplished.

Considering the importance of continually gathering information in a design activity and how it yields a better-quality design in Student 64's response, we find that what they consider "crucial" for achieving "quality" stems from what they notice, which is then directed by design intentions. As Student 64 establishes relationships among design activities to explore how they are meaningful and useful for achieving quality in their design takeaway, we see how this exploration is validated in the third question as an implementation intention. The design timelines help students recognize patterns related to the specific elements of design. At the same time, they also present design outcomes related to the varying levels of design expertise. Identifying the design elements, such as gathering information, and how they get instantiated in low, average, and high quality designs enables students to discern which strategies are productive for ultimately achieving high quality designs. In doing so, this not only highlights the value for critical exploration but also how this newly acquired information can be appropriated and become part of a students' value system [30]. While Student 64 expresses intrinsic motivation (that is, having a sense of personal reward) when modeling, their design attitude shifts based on newly acquired information towards an extrinsic motivation (that is, engaging in an activity to obtain an outcome) - achieving quality. Framed as an implementation intention in question 3, Student 64 highlights the instrumental value in "continually gathering information" along with the other design activities to attain the same outcomes as an expert. From self-determination theory, Deci and Ryan [31] view this instrumental value as motivationally rewarding that, in turn, directs behavior that follows how experts engage in design. This suggests that Student 64 adopts an intrinsic goal that has the potential to influence how goal setting, planning and motivational beliefs may further their learning efforts. From research findings examining differences between intrinsic (vs. extrinsic) goals and autonomy-supportive (vs. controlling) learning climates, Vansteenkiste, Simons, Lens, Sheldon, and Deci, [32] found that students adopting an intrinsic goal displayed greater persistence, deeper learning, better transfer.

If we consider Student 35's responses in relation to what they deem "crucial for success", we see that the design timelines played a different role. While the design timelines raised Student 35's understanding of problem scoping/problem framing ("realizing that higher quality designs gather data and define the problem more thoroughly BEFORE modeling"), the remainder of their response highlights a different value-related perception. Because the design timelines show empirical evidence that is "statistically relevant", we see that Student 35 values what the properties of the timeline representations can afford them, that is, to "PROVE to people that understanding the problem FIRST is crucial for success." This perception is contrasted with how we have seen other students attribute value to the design timelines to improve their approaches to design. Although our data does not allow us to expound on this point beyond what the student has written, it does, however, suggest that from their response to question 3, their prior design experiences match what they are noticing from the design timelines and formally confirms their personal beliefs and extrinsic value about the importance of "understanding the problem FIRST."

TABLE 3 Selected Student Quotes for Design Codes Occurring Across Question 1 and 3

Breadth and Iteration/Transitions	
*Question 1: *"Importance of going back & forth different phases in design process to deliver high quality work."* (Student 15, 322B)	**Question 3: *"If I start focusing too much on one aspect of design, I will remind myself to shift gears and reconsider my approach."* (Student 15, 322B)
Time	
*Question 1: *"It was interesting to see how time, expertise, experience, and design approach all contribute to varying levels of quality. Although I've had the opinion that more time spent doesn't always mean higher quality work, in this example that didn't seem to be the case."* (Student 23, 322B)	**Question 3: *"Take my time, Gather all the information throughout the modeling phases."* (Student 23. 322B)
Gathering Information	
*Question 1: *"*ideal ways to sequence the design process. I tend to enjoy modeling more than the other tasks but now I see that it is more important to scope the project before jumping into the model *the more transitioning between tasks, the better the quality, This goes to show that gathering information and other tasks should continually happen and that checking/rechecking work is crucial!"* (Student 64, CE17)	**Question 3: *"Yes, through using different elements of the design process throughout, the design of the project. Continually gathering information, analyzing, generating ideas, communication and making decisions."* (Student 64, CE17)
Problem Scoping/Problem Framing	
*Question 1: *"Realizing that taking your time is important, realizing that higher quality designs gather data and define the problem more thoroughly BEFORE modelling which is SO COOL to see as statistically relevant because now I can PROVE to people that understanding the problem FIRST is crucial for success."* (Student 35, CE17)	**Question 3: *"Not really, because I believe I would always have generated ideas/gathered info throughout the process."* (Student 35, CE17)

* Question 1: *"What are the most important things you learned today? Why?"*
** Question 3: *"Will information from this exercise affect how you will do design in the future? How?"*

Design Intentions

Design intentions are characteristics of metacognitive regulatory skills and include planning, monitoring, and evaluating. Planning entails selecting strategies and assigning resources that influence performance and entails strategies and allocating time or attention selectively [19]; [5]. Monitoring, like self-observation, refers to one's cognitive tracking of personal functioning and task or context. Evaluating entails a form of self-judgement against a standard.

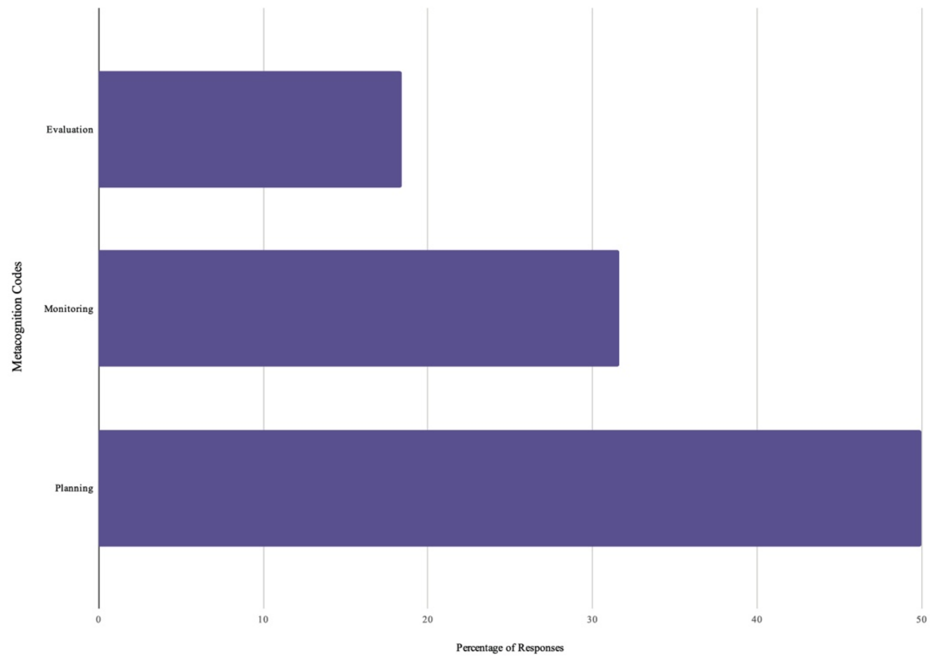


FIGURE 4. Metacognition Codes for Question 3: “Will information from this exercise affect how you will do design in the future? How? Percentage of student responses (n =73)

Figure 4 shows the overall percentages of the metacognition codes used to code student responses to question 3, “Will information from this exercise affect how you will do design in the future? How?” Below we describe example responses represented in the figure.

Planning: Figure 4 shows that 50% of the responses indicated student intentions to plan on how they will design in the future (Note: Question wording invites students to respond with planning activities). Generally, student responses were framed either as an implementation intention or as goal intentions [1].

Implementation intentions expressed a goal-directed behavior and an anticipated situational context. For example, *“I will pay more attention to how much time I spend on each design activity. Next time, I might try setting a timer to help keep the team on track”* (Student 7, 322B).

The students’ goal-directed behavior entails paying more attention to how much time they spend on each design activity. In order to pay more attention to time, the student intends ‘setting a timer’ the next time they do design. The anticipated situational context is to ‘keep the team on track.’ Goal intentions entail end states; such as, *“I will spend a lot more time on modeling” (Student 9, 322B).*

Monitoring: In Figure 4, 32% of student responses represented monitoring aspects that are consistent with those outlined by Zimmerman and Paulsen [8]. These insights provided a nuanced understanding of how they intend tracking specific performances, the circumstances, and the outcomes in doing design in the future. For example, students’ intentions to track their performances were expressed as mental processes such as “I will be more aware” or “I will always remember". These monitoring strategies described circumstances such as "if I start focusing too much on one aspect of design…", and outcomes as evidenced in the following quote:

"Yes, from now on I will be actively looking for new areas of the design process that I do not engage in as much and trying to balance my time spent in each." (Student 5, 322B)

One insight further indicated the limitations of this activity and that there are constraints beyond the design activities that should be considered, as illustrated in the following quote, *"[t]his activity just told me how planning is vital for a better quality design. It doesn't help much if I have to stress about a lack of human resources, time, or material constraints."* (Student 53, CE17) These constraints, in some instances, entail resources and emotional reactions.

Evaluation: The timeline representations enabled students to evaluate their design processes against the varying levels of expertise and form goal intentions related to quality that is consistent with how experts engage in design. While only 18% of the student responses represented the metacognitive code evaluation, we found that students used the timeline representations as a form of feedback and that the amount of time spent, along with other design activities, is directly reflected in the quality scores. For example,

"Help allocate my time and resources to a range of <illegible> that overall will contribute to a higher quality design" (Student 61, CE17).

Overall, students used their previous performances as a criterion for self-evaluation as well as what Zimmerman and Campillo [15] term a mastery criterion which refers to comparing outcomes to those of experts.

These three self-regulatory strategies that relate to metacognitive skills were often described in relation to the design activities. The following findings provide more nuanced insights into how students intend doing design in the future. We present pairings that occurred frequently in the student responses, highlighting what students report on based on the in-class activity and other thoughts that were characterized as the three metacognitive skills.

Metacognition and Design Activities

Planning in relation to Time. Some of the most notable insights were how students talked about planning in relation to time and the spread of design activities that were coded as 'Breadth', for example,

"I will pay more attention to how much time I spend on each design activity. Next time, I might try setting a timer to help keep the team on track" (Student 7, 322B).

The use of time is viewed as regulating behavior where students' intentions entail behavioral control. In Student 7's case, efforts to focus and optimize their design intentions entails improving on their attentional control using 'a timer.' In making plans, time is also viewed as effort control [6] where students form intentions about distributing their time and efforts across design activities.

Planning in relation to Modeling: Spending and spreading time out generally or specifically to a design activity was expressed in relation to modeling, where students intend 'not getting stuck in modeling.' For example,

"I will make sure to break up the time spent modeling to check other aspects of the problem. I will make sure to gather a lot of information/ideas in the beginning before I start modeling" (Student 40, CE17).

The design timelines provide students with the opportunity to observe varying levels of design expertise. As a result, their intentions to move beyond modeling and take time before engaging in modeling aligns with how experts would engage in design. In addition, from the responses, we found that a strategy students intend using when getting stuck in modeling is to iterate or transition to other aspects of their design before and after modeling.

Planning and Monitoring: The relationship between planning (50% of responses) and monitoring (32% of responses) was another aspect that students expressed. For students, monitoring their personal functioning in relation to their engagement in design was expressed by mental processes. Students used mental processes to articulate how they would approach planning and monitoring stating that it was important "to consciously go back", "to remind me to always go back to the user in the end", "to focus on things I know I struggle with like communication, defining the problem", to "remember to not get stuck in any single process…instead try to flow more fluidly" and "make me think about how much time I am spending on the design process." In addition to tracking their personal functioning in the task, student responses also included their emotional states while engaging in the design process. Students articulated "not be afraid to go back" in relation to iterating and/or transitioning between design aspects. Instances where students did mention affect and emotions, suggests they are self-regulating or attempting to control their affect and/or emotions using self-regulatory strategies [6]. For example,

"Yes I will spend more time gathering information and ideas and not be afraid to go back to these steps. Also spend more time in the other fields like feasibility, analysis, decision" (Student 57, CE17)

For this student, not being afraid to go back to gathering information suggests they intend to control for self-efficacy. Zimmerman and Campillo [21] refer to self-efficacy as a self-motivation belief where a student's personal beliefs entail having the means to perform effectively in a task using positive self-talk [9] as evidenced in the student quote.

Planning and Evaluation: For some students evaluating their design processes to achieve higher quality scores while designing was another metacognitive aspect present in the responses (18% of responses related to the code 'Evaluation'). Students articulated that in their future designs, they would "modify and refine", "use design envelope strategy for distribution of tasks", and "amend the differences between my design style and the high-performance designs." These were based on what they learned from the in-class activity, particularly referencing the high-performing first year and senior graduating timeline representations as a standard of performance.

Monitoring and Evaluation: We also found that in relation to monitoring and evaluation, students who mentioned some process of monitoring took a further step in articulating an evaluative aspect. For example, one student stated

"Yes, it will improve it [my future designs], as now I'm aware that by only modeling without having clear ideas, I would fail." (Student 44, CE17).

Other students expressed similar self-observations, such as *"Yes, I'll be more active checking my designs and trying to bring in new ideas, rather than sit in a puddle with just a few ideas"* (Student 45, 322B)

In these instances, students articulate how the act of not 'having clear ideas' or 'bring in new ideas' would result in a failed design or an unfavorable situation like sitting 'in a puddle with just a few ideas.' This suggests that students are noticing their engagement in design aspects but also that there are repercussions for their actions in relation to their performance.

Discussion

Student takeaways from question 1 highlight some of their perceptions and understanding about design and the in-class activity. From the in-class activity, students predominantly emphasized the importance of breadth, iteration/transitioning, gathering information, modeling, and problem scoping/problem framing. The distribution and use of time across design activities was another aspect that was foregrounded in the student responses. The timelines presented in the worksheet and lecture functioned as a form of feedback where students were presented with varying levels of design expertise. From the student responses, we found that students used the high-performing first year and graduating senior engineering students' timelines as a model for processes that emphasize different design activities. For example, students placed emphasis on breadth over depth and in relation to time.

In order to obtain a more inclusive perspective on student learning that includes what they took away from the in-class activity in terms of their thinking, motivation, affect, and context, it is useful to take a self-regulated learning perspective. From this perspective, students are positioned as active participants in the learning process where they have the opportunity to construct their own meanings, goals, and strategies from their situational context. Students are also positioned to potentially monitor, control, and regulate aspects of their own cognition, motivation, behavior, and to an extent their contexts. Consequently, students can regulate their learning in a manner that enables them to set goals and assess their learning or performances against a set of standards across contexts. Accounting for students' thinking, motivation, and behavior, a self-regulated learning perspective considers these characteristics in relation to contextual factors, learning, and achieving outcomes [6].

In developing students' self-regulatory skills, from question 1 students provide explanations for what they considered the most important thing they learned from the activity. In doing so, Schunk [33] explains that attributions for previous performances impact how students may think about an upcoming task – in this context, how they might engage in design in the future. In addition, it may influence the kinds of goals students may set and their approaches to design.

Student responses to whether the in-class activity will affect how they will do design in the future provide deeper insights into students' self-regulatory skills as the question primes students to plan for their future learning. As emphasized in the first question, students re-emphasized breadth. In their responses, we found that students evaluated their personal outcomes and then made adaptive inferences. In ill-defined problem-solving contexts, adaptive inferences refer to conclusions about how to modify a current approach to obtain a solution or outcome [21]. From the student responses, we saw that students ultimately intend adopting expert ways of doing design. As a result, student responses can be interpreted as adaptive inferences where they selected and articulated effective strategies relevant to their needs. Students' adaptive inferences provide educators with insights into how students might behave.

The intended design strategies students articulated were often coupled with affective reactions that stemmed from their previous experiences doing design. In order to optimize their future behaviors in doing design, students articulated self-control processes. From these processes, the affordances of the in-class activity are made visible. The timeline representations present a visual representation of the varying levels of design expertise from which students may use as a model, where they are able to discern what counts as quality and what processes and behaviors are included to achieve a high-quality design.

Another self-control process that is made visible from the in-class activity is what students selected to focus their attention on and articulate task strategies. Student responses made explicit ways to control for behaviors by articulating techniques. One example that stands out is how students intend controlling and monitoring their use of time. Such insights provide educators with insights into how they may best support students in doing design while developing their self-regulatory skills. Consequently, students can establish self-criteria where they are able to monitor and self-evaluate their progress, thus enabling students to be active participants in their own learning that is coupled with self-satisfaction.

When we consider the nature of students' design intentions, the responses were framed either as implementation intentions or as goal intentions. It is important to note that student responses were framed as plans because the question primed students to respond in such a manner. Having students articulate their future plans is akin to forming implementation intentions where students articulate how they intend achieving the goals they set out in their planning. According to Gollwitzer [1] planning activates a general cognitive orientation that facilitates the initiation of goal-directed behaviors. Viewed as an affordance, Gollwitzer [1] explains that this relates positively to student commitment in implementing their goal intentions in the future. This, in turn, enables students to monitor their performance and learning and ultimately self-evaluate based on various criteria in the future.

Student responses coded with the metacognitive code 'Monitoring' show that students have affective reactions to the current ways in which they design. From the responses, students draw upon their affective reactions to their performance while intending to monitor their emotional experiences when engaging in design in the future. Thus, students use their emotional reactions of the task to modify their future preparedness [34].

Providing students with the opportunity to become aware of how experts engage with design provides students with choices. The activity provided students with feedback on how they could engage with design. In doing so, they are given the opportunity to decide what to do next. Overall, students' subjective task values predict both intentions and decisions to persist at different activities [35].

The variation in student responses also highlighted that design is a complex process that foregrounds a multitude of ways of doing, feeling, and being. Consequently, this type of in-class activity affords design educators with a way to see the variance in what students perceive as relevant within a design classroom, a design activity, and beyond.

Limitations and Future Directions

While these results report on student perceptions, the use of this in-class activity as a tool for engaging with students and their design process within a classroom activity affords educators new modes of thinking on how to either hold students accountable to their intentions or develop behaviors and habits that would assist in developing quality design in the future.

This is an activity that is introduced and conducted in a class setting in approximately one hour. This research could be expanded into assessing the use of design timeline models as a type of instructional tool used within a project-based curriculum used throughout an entire project. This design activity is introduced and conducted within one class period, what might we learn if students are able to engage in this kind of activity over time within the context of an ongoing design project? The activity asks students to ground what they learned in past experiences "Reflect on how you have done design in the past". However, comparing the timeline representations to past experiences requires students to have been very aware of design activities and time. One of the affordances of the timeline representations of design process is that they draw attention to how time is spent in a way that is not well articulated in the prescriptive node-sand-arc representations of design. What further insights might students learn if they engaged in this kind of worksheet throughout a design process? Might they be able to relate the abstract concepts like "problem definition" to instances in their project. A direction of future work is to include the use of variations of the worksheet during a student design project, such as a capstone class, where students might be able to engage multiple times and reflect on whether they are executing their intent.

While this research is based on students' intentions to plan and change behaviors, a future direction is to conduct a study on how to change these intentions into design behaviors and actions. Having intentions to build productive design habits can also be the basis to develop design behaviors - in one instance a student reported the use of using a timer to track when shifts in the design process where needed. Extrapolating on this idea, creating habits, tools, or systems that allow easier tracking of design steps could be a future direction of interest.

Further directions of this research can be enhanced through the methods, frameworks, and practices introduced by Patrick Cunningham and his work around metacognition within engineering education [36].

This study reports on student responses from two classes in two different engineering departments at one university. Future work might look too what is happening in engineering in education also look across multiple engineering disciplines at multiple universities to see how students are engaging in metacognition around design intention. Differences across disciplines may provide insights into different strategies and design understandings.

Conclusion
In this study, we analyzed data from 73 students from two different classes in a college of engineering in a large public research-intensive university who participated in a classroom activity that took approximately 50 minutes long. After learning about design processes of engineers with various levels of expertise and responding to questions about what they found to be important information, students were asked 'Will Information from this exercise affect how you will do design in the future? How?' From coding their responses, we learned that students are thinking metacognitively about design by articulating plans, managing time efficiently, monitoring their steps, and evaluating their design process. While all students can articulate their design intentions, some demonstrate a refined understanding of their design intentions and actionable strategies that could directly impact how they design in the future.

This practical classroom activity can be used at the beginning of time intensive design experiences (such as term-long design projects or capstone design courses) to help students develop a targeted understanding of important aspects of the design processes and set intentions for how they will engage in their design projects.

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[Note: If you are interested in using the classroom activity described in this paper, please contact Cindy Atman at atman@uw.edu]

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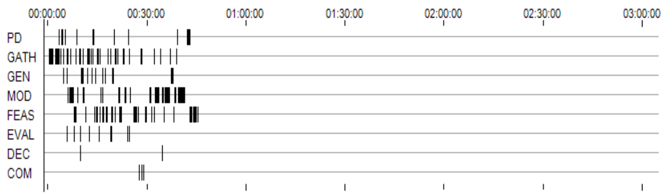
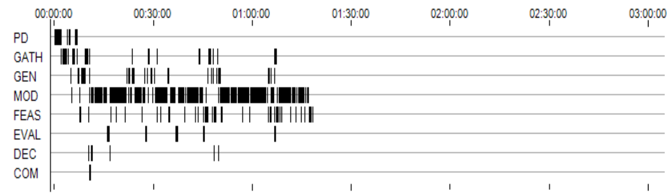
Appendix

Design Timelines

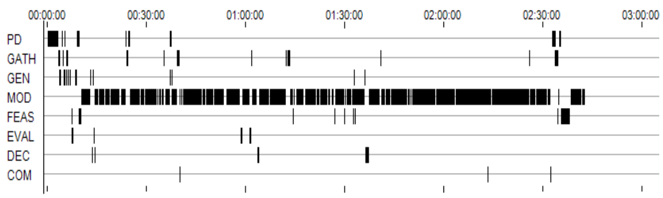
First Year #1 (Quality Score = 0.37)



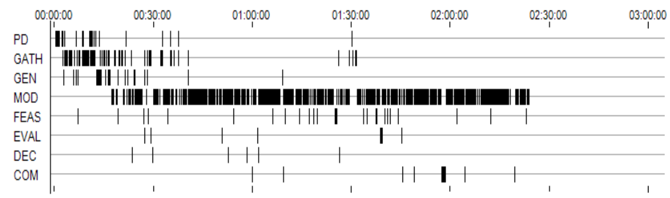
Graduating Senior #1 (Quality Score = 0.38)



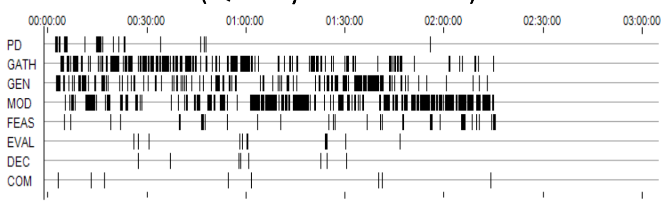
First Year #2 (Quality Score = 0.45)



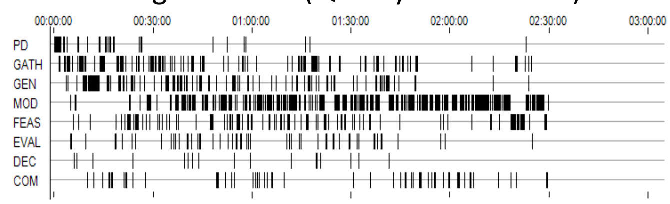
Graduating Senior #2 (Quality Score = 0.53)



First Year #3 (Quality Score = 0.62)



Graduating Senior #3 (Quality Score = 0.63)



PD:	Problem Definition
GATH:	Gathering Information
GEN:	Generating Ideas
MOD:	Modeling
FEAS:	Feasibility
EVAL:	Analysis
DEC:	Decision
COM:	Communication

Part I: Design Timelines Activity

A Individual: In the design process timelines shown on the first page:

- What similarities and differences do you see between the first year and graduating senior engineering students?
- Do these similarities or differences also involve the quality scores? How so?

B Group Discussion: Is there anything you would like to add to item A from your group discussion?

C Presentation/Class Discussion: Is there anything you would like to add to item A from the presentation/class discussion?

Part II: Design Timelines Reflection

A: What are the most important things you learned today? Why?

B: Reflect on how you have done design in the past. Does that differ from the design processes you just learned about in this exercise? How?

C: Will information from this exercise affect how you will do design in the future? How?