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# Using Design Process Timelines to Teach Design: Implementing Research Results

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## Abstract

While design has been increasingly taught in engineering courses over the last decade, there are still many opportunities to improve the effectiveness of design learning. One opportunity is to leverage research on design processes in classrooms as design is taught. This paper presents student work from two instances of a small seminar course in which empirically-based design process timelines were used as the basis of teaching undergraduate engineering students about design processes. 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, constructed with data from individuals with varying levels of design expertise, present salient information about how individual design processes can differ. We have developed a series of tasks based on these representations whose purpose is to teach students about design processes, and we implemented them with eight undergraduate engineering students in two separate research seminars at a large state institution.

Specifically, in these tasks, students were presented with design timelines as well as the empirically-based codes that were used to construct the timelines, and were asked to develop new representations from that data (an activity called Design Brief 1, or DB1). They were then asked to execute a design task, capture their own design process, and then create a representation of their personal design process (an activity called Design Brief 2, or DB2). Finally, at the end of a quarter that included the above tasks plus tasks to consider additional design issues such as context and perspective, students were asked to create a "memory aid" to capture important aspects of the design process that they wish to take with them to their future design experiences. In this paper, we present the work that the students turned in for the design projects. We also present a mapping of the students' work to the elements of the design process presented to them in the design timelines to provide insights on the impact of the use of the timelines to teach design.


## Introduction*

Extensive research in the learning sciences has demonstrated that "[h]ow students organize knowledge influences how they learn and apply what they know" [2, p. 4]. Furthermore, if students organize their knowledge about a topic in a meaningful conceptual framework, they are more likely to be able to transfer what they have learned into a new context [3]. One way to provide learners with a meaningful conceptual framework is through an advance organizer, presenting learners with information about the topic they will be learning that is structured in a way to facilitate learning [4]. The use of advance organizers (both textual and graphical) has been an educational strategy for some time. A Google search for the term "advance organizers" returns 84,400 results. A typical online entry, such as that of the Teaching Online Pedagogical Repository from the University of Central Florida's Center for Distributed Learning, provides a

* Portions of this section are adapted or excerpted from [1].

concise definition: "Advanced organizers are frameworks for helping students understand what it is they'll be learning" [5]. Advance organizers can be presented in multiple formats, which can be broadly classified as text or graphic organizers. Graphic organizers can be particularly effective in conveying an underlying structure for abstract concepts. A graphic organizer is described by the National Center for Accessible Instructional Materials as "…a visual and graphic display that depicts the relationships between facts, terms, and or ideas within a learning task" [6].

For teachers of engineering design, an important question then becomes "what is an effective graphic organizer to help students develop their understanding of design processes?" There are many published design process models (for example, see [7]). Many of these models are abstract and prescriptive. These properties can make them difficult for novice designers to interpret and put into practice. In this work we propose to teach engineering students about the activities associated with design using advance organizers that are empirically-based, descriptive representations of the design process. Specifically, these representations are presented in the format of timelines of design activities that individuals engage in as they solve a design problem.

A second finding from the learning sciences that is leveraged in this work is that learning is enhanced when learners translate information from one representation to another. Halpern and Hakel [8, p. 39] describe the finding this way: "learning is generally enhanced when learners are required to take information that is presented in one format and 're-represent' it in an alternative format." In the learning experiences we present in this paper, we have incorporated the use of both advance organizers and translation, and we use our past research on design processes as the starting point for the tasks in which the students engage.

## Our Past Research on Design Processes*

Research has demonstrated that engineers with different levels of experience (first-year students, fourth-year students, and expert practitioners) exhibit different patterns of design activities when they work on a design problem [9, 10]. These different patterns are made visually apparent when they are displayed as timelines that indicate time spent in different design activities and number of transitions among design activities. Timelines for a large number of experiments conducted in lab-based settings are able to convey the different patterns of activity, such as gathering information, modeling, and communicating results, that characterize different levels of expertise. The adopted design framework and a sample design timeline are provided in Figure 1. The quality score in the figure is a score (ranging from 0 to 1) that was based on an evaluation of the final design produced by the participant. Scores typically ranged from about 0.3 to 0.7.

* Portions of this section are adapted or excerpted from [1].

| DESIGN STAGES | DESIGN ACTIVITIES |
|---|---|
| Problem Scoping | (Identification of a Need)<br>Problem Definition (PD)<br>Information Gathering (GATH) |
| Developing Alternative Solutions | Generation of Ideas (GEN)<br>Modeling (MOD)<br>Feasibility Analysis (FEAS)<br>Evaluation (EVAL) |
| Project Realization | Decision (DEC)<br>Communication (COM)<br>(Implementation) |

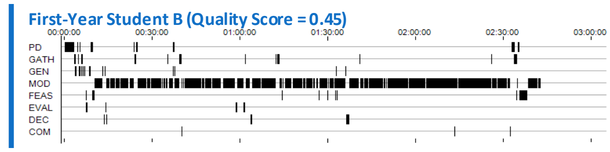



**Figure 1: Design Framework and Example of a Design Timeline**

In previous work using a research-to-practice model to teach undergraduate engineering students about design processes, we adopted a classroom activity that utilized design process timelines resulting from analysis of the activities that design processes entail [11]. After only a 30-minute session in which three examples of timelines from first- and fourth-year students were examined, undergraduate engineering students were able to make substantial observations about the design process, such as:

> *"Success is strongly correlated with gathering data and defining the problem early on."*

> *"Problem definition is key to the overall project. Remind yourself of what you are doing and what is really being asked. Pick your head up from the paper (modeling!) and analyze the problem."*

Another student compared the "Graduating Senior" timeline shown in Figure 2, below, to those of other students and concluded that an effective design process might be characterized as having a particular shape that he labeled an "Ideal Project Envelope." The ideal project envelope is something our researchers previously identified and called a "cascade pattern," seen most often in experts' timelines. This cascade pattern contains a full range of design activities and suggests a way of moving through those activities over time. Importantly, for experts and the more proficient senior students, significant time is spent in early problem-scoping activities, such as information gathering and considering the larger context of the problem.

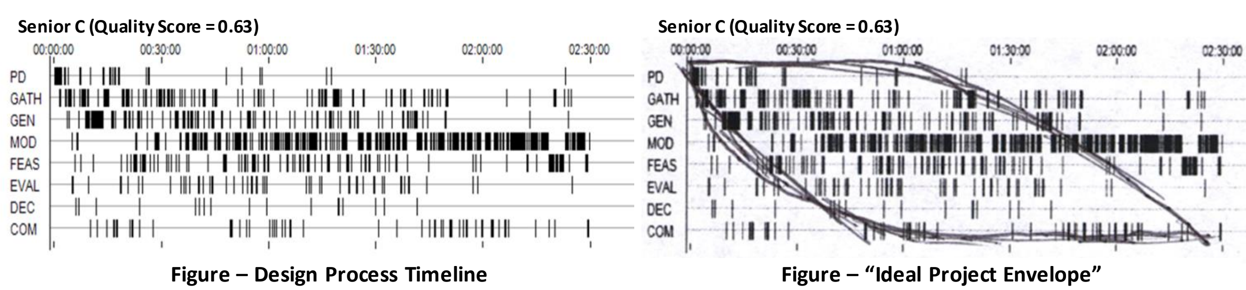



**Figure 2: Design Timeline Showing "Ideal Project Envelope" [Figure reproduced with permission from [11]]**

With such insights resulting from just a short class exercise, we wanted to investigate how a more in-depth interaction with the design process timelines might impact learning about the design process. Our intent was for the design process timelines to serve as advance organizers for students, providing a structure that could facilitate student learning and transfer of design concepts from one task to another. One author (Prof. McDonnell) developed a pair of design briefs in which students create visual representations of the design process, first using the data represented in the timelines described above, and second by completing a design task themselves and developing a new representation of their own individual design process. Students in a Master's program for Graphic Design at the Central Saint Martins (CSM), University of the Arts London engaged in the two design briefs and developed representations that were both creative and effective in conveying multiple aspects of design processes [12]. We wanted to see the representations students from other majors, including undergraduate engineering students, would create if they engaged with the design briefs. Another author (Prof. Atman) included the two briefs with several other tasks in a seminar-type course titled "Design Your Own Design Process."

In the rest of the paper we present (1) a brief description of the teaching/learning materials we created and the courses in which they were used with engineering students (full details are presented in technical reports [12-14]), (2) a description of the representations created by engineering students for three tasks, and (3) the results of a qualitative analysis that compares the concepts displayed in student representations to the concepts embedded in timeline representations that they engaged with in the course.

## Description of Undergraduate Engineering Course*

The initial course materials were developed as part of a small workshop conducted at the Central Saint Martins (CSM), University of the Arts London, for which two design briefs were created and implemented [12]. These design briefs were then used in two offerings of a research group seminar at the University of Washington (UW), Seattle, in which undergraduate students in pre-engineering and the department of Human Centered Design & Engineering enrolled for elective course credit. The course was advertised to all current and prospective students in the department, which is comprised primarily of junior and senior students (few 1st and 2nd-year students are directly admitted to most engineering programs at this school). Three students participated in the first offering of the course, which occurred January to March of 2013, including one female and two males. The second offering, which occurred September to December of 2013, enrolled five students, including three females and two males.

Given the range of course experience and potentially non-academic design experience that was possible in a course like this, the materials and activities were designed to be meaningful and relevant to all students, and thus to be useful while navigating both college and professional experiences. Students who participated in the research groups developed a representation of their own design process based on the activities described below, and had the opportunity to reflect on how these activities could be integrated into a personal vision of design both individually and via interactions with their peers in the research group.

The main activities of the course had students:

- Write a description of their personal definition of design, which they then updated after completing each subsequent activity

* Portions of this section are adapted or excerpted from [1].

- Describe various design models found in the literature
- **Interact with empirically based representations of design processes and create their own representation**,
- **Complete a design task and create a representation of their personal definition of design (visual, auditory, dance performance, etc.)**
- Respond to tasks designed to elicit understanding of design context and articulate a definition of context with regard to their personal definition of design
- Reflect on different perspectives that can affect perceptions of design processes and articulate a definition of perspective with regard to their personal definition of design
- **Design and produce a "memory aid" (e.g., ear worm, mantra, meme) to reinforce their personal design process representation over the long run:**
  - **Determine and document what aspect of design/design process they would like to remember over the long term**
  - **Develop and document a way to remind themselves about these aspects of design**
- Compile a technical report with the written artifacts described above from each of the individual students (see [13, 14])

The January version of the class included one additional assignment in which students considered the Louis Pasteur quote "Chance favors the prepared mind" [15] with respect to their professional goals, read some articles that presented various perspectives on ethics, and related both of these concepts to their understanding of design.

*Description of Assignments*

The three elements of the class that are the focus of this paper are indicated in bold font in the list above and described in more detail below:

1) Design Brief 1: Representing a Design Process from Data

In this activity, which we refer to as Design Brief 1 (DB1), students were provided with previously recorded design timelines from a talk-aloud protocol performed by engineers as they completed a playground design task (see [9-11]). Figure 1 above illustrated the design framework and a visualization of one of the nine sample design timelines provided to the students. The students were introduced to the timeline representation with the same in-class exercise (taking about 20 minutes of class time) that was described in [11]. In this exercise the students learned about the timeline representations and empirically based differences across first year engineering students and graduating engineering students. They then received a two page handout (Appendix A) that presented research results comparing first-year students, graduating students and expert engineers. It also presented selected insights from previous students responding to the timelines, including the representation of "the ideal project envelop.". The task the students in the current course were asked to complete was to create alternative representations of these timelines choosing any combinations of media and formats such as, 2D print, 3D construction, sound, video-recording, or performance. The intent of this task was for students to see different ways that design activities can be woven together in different design processes, and that designers with various levels of experience tend to exhibit different characteristics in their processes. In this task, students studied experimental findings (that were serving as advance organizers for the design process), *selected* the findings they wanted to highlight, and *translated* them into a new representation.

2) Design Brief 2: Representing Your Own Design Process

In this activity, which we refer to as Design Brief 2 (DB2), students were asked to capture their own design processes as they completed a 2-hour design task, such as creating a poster for an art exhibition or a conceptual design for a bridge. The students were then asked to represent what they had recorded from their own design process, again using any form of representation. In this task, students *designed* an artifact, *reflected* on their own design process, *selected* elements of their design process they wanted to highlight, and *translated* them into a new representation.

3) Creating a Memory Aid

As a culminating assignment for the course, students were asked to create a "memory aid" or "*ear worm*" that would represent the insights about the design process that they learned in the course. The memory aid was intended to be something that the students would refer to in future work, to reinforce specific aspects of the design process that were important to them. [Note: in the January offering of the class the students were asked to create an "ear worm", which is a term for a song that gets stuck in your head. The intent was to draw a parallel for them to create a representation of the design process that would get stuck in their head. In the September class the students were asked to create a "memory aid", which included "ear worm" as a way to define the term.] In this task students were asked to *reflect* on all the topics they learned in the class, *select* important aspects of design they want to highlight, and *translate* them into a new representation.

**Describing Student Work**

In this section, we present a selection of work from the eight students who participated in the two offerings of the seminar at the University of Washington. Each student created very different artifacts and had different takeaways and lessons learned from the course. Table 1 provides a thumbnail overview of student work for the three assignments described above, namely: (a) Design Brief 1: Representing a Design Process from Data (DB1), (b) Design Brief 2: Representing Your Own Design Process (DB2) and (c) Design Your "Memory Aid."

It is suggested to readers that you pause at this point, and before looking at the student representations presented in Table 1, look back to the timeline in Figure 1 and think about what types of representations you would expect undergraduate engineering students to produce. Then turn to Table 1 to view the actual products of their work.

As a whole, the students' visual representations were rich and varied, and displayed that, through these tasks, the students were able to develop an appreciation of the complexities of the design process. The creative and multifaceted representations that the students developed are evidence of student engagement in the tasks. They took the assignments seriously and put significant effort into their work, particularly in light of the fact that the 2 credit course was pass/fail.

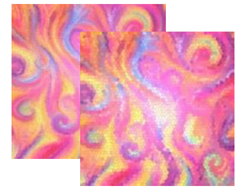
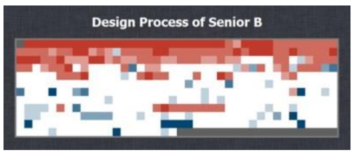
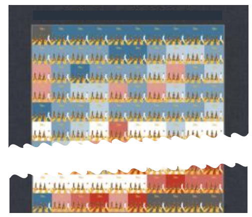
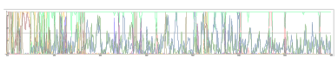
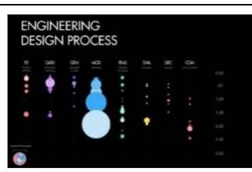
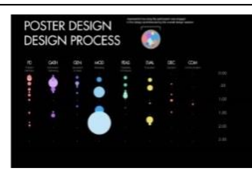
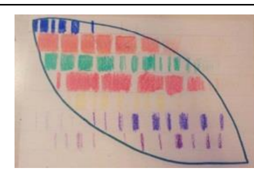
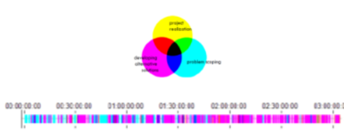
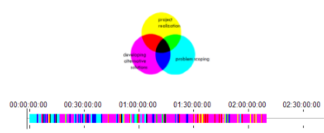
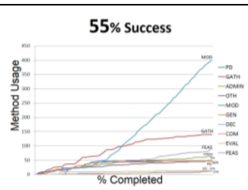
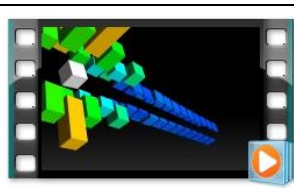
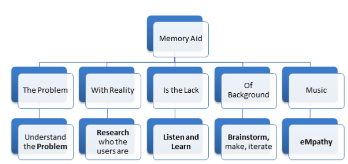
The next section presents the representations with larger graphics, and provides a description of each piece, but first we present an overall description of the student work for each task. Viewing the student work for the DB1 task presented in the first column of Table 1, one thing that is striking is that the representations are quite creative. In developing their representations, the students were thinking broadly, and not just producing a literal translation of the original findings. The students' representations are not similar to each other, as they might be if they were closer to direct translations of the original data. The task provided an opportunity for students to showcase their creativity.

Moving to the second column in Table 1, the DB2 representations that the students developed again display both creativity and the ability to move beyond "the literal." Recall in this task that the students were representing their own design process, and they made a variety of choices when they created their representations. Three students (Cathy, Leah and Anne) chose to represent their personal design process with the same visualization that they used for DB1. This enabled them to make a direct comparison of their own process to the one from the original data. Some students chose to develop new representations that could highlight different aspects of design than their DB1 representation. In several instances, students were inspired by their classmates' DB1 representation and incorporated some ideas from their classmates into their DB2 representation.

Inspecting the third column in Table 1, the students' memory aid representations again displayed significant engagement and imagination. Three students built on elements of their previous representations, adding noteworthy elements to transform them (e.g., Cathy adding music and animation, Karl making a concrete representation into something more abstract, Anne taking a 2D image and making it into a 3D physical object). The other students created new representations that either highlighted a different aspect of the design process (Leah) , made a physical object (Karl), chose to include a number of new elements of design and context (Scott), focused on a quote that conveys a meaning that was discussed throughout the class (James), or mapped a quote that was meaningful to her to elements of the class that she wanted to remember (Beth).

It is difficult with the thumbnail representation of the student work to adequately understand and appreciate the thought that the students put into the work. In the sub-sections that follow, we describe each student's artifact by summarizing, paraphrasing, and sometimes quoting the students own writing from the technical reports. Note that these descriptions vary in their length, focus and level of detail due to the variety of student contributions to the technical reports.

**Table 1: Thumbnails of Student Work**

| Student | Design Brief 1 | Design Brief 2 | Memory Aid |
|---|---|---|---|
| Cathy |  |  |  |
| Karl |  |  |  |
| Tim |  |  |  |
| Leah |  |  |  |
| Scott |  |  |  |
| Anne |  |  |  |
| James |  |  | "The harder I work, the luckier I get." |
| Beth |  |  |  |

*Cathy's Design Process Representations (DB1 and DB2) and Memory Aid* *

Cathy created digital paintings to visualize design processes. In these, specific colors were used to represent different aspects of the design process, about which she wrote:

> *"I assigned the warm colors (yellows and reds) to the activities, typically at the beginning the process, like problem definition and gathering data. The colors move to cooler shades as the process continues, pink being the middle color represented modeling, and the coolest color of blue and green wrapping up the process with communication and decision making. The larger the space occupied by the color, the more time spent on that certain task. I wanted to mimic the tear drop shape from the original data in my art piece as well so my timeline starts from the upper left corner and flows diagonally to the lower right. ... [The] ability to jump from category to category meant ... looping back gathering more data or redefining the problem based potential roadblocks during [the] design process. This is why I incorporated so many looping elements in my painting. I also tried to give the illusion of depth to the piece because ... some-times the loop may lead to a dead end, or may spiral into something completely new, that is why some of the swirls in the painting lead nowhere and some lead to cooler (more conclusive) colors, signifying that that idea is part of (or lead to) the final product."*

Figure 3 shows her design process visualization of a fourth-year undergraduate student's design process (Senior B) from the timeline data she was given in DB1. Figure 4 shows the visualization of her own design process from DB2.

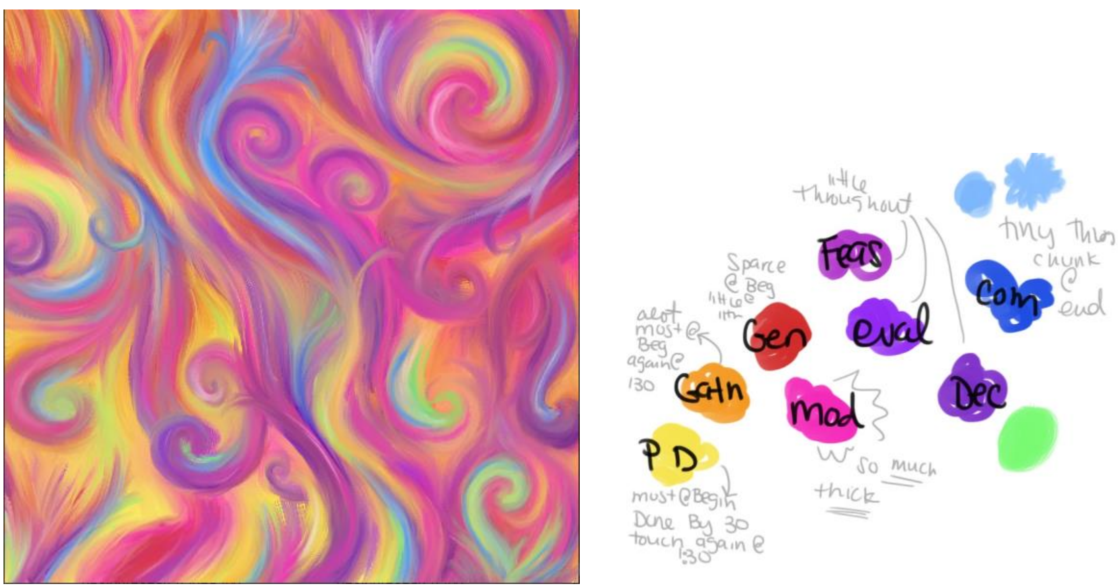



**Figure 3. Cathy's Representation of Senior B's Design Process from DB1**

* Portions of this sub-section are adapted or excerpted from [1].

**Figure 4. Cathy's Representation of Her Own Design Process from DB2**

Cathy's memory aid built upon her paintings, adding musical accompaniment, mosaic versions of the paintings, and a brief textual definition of design. The music selected was two different renditions of Debussy's "Arabesque":

> *"The written piece of music is like the initial idea, it can be given to one group of designers and artifact A will be created, give that same idea to a different group of designers with different experiences different perspectives (etc.) and an entirely different artifact will be created. Just [like] with a song, give it to a single pianist and you'll have one beautiful rendition of the song. Give it to an orchestra and you'll have an equally beautiful but vastly different experience & display."*

The visual component of her memory aid included the original paintings of Figure 3 and Figure 4, plus mosaic versions of each, which are shown for Senior B's design process in Figure 5 and for her design process in Figure 6, below. As she explains, the mosaic tiles indicate pieces of a whole:

> *"The version with the larger and fewer pieces represents the idea that with less collaboration you're seeing less of the whole, and the rendition with more and smaller pieces represents the group getting closer to the cohesive and completed final product. With the bigger pieces you're not able to see as much of the underlying swirls and thus missing out on details that come into play in the final product. Both the classical song and these tile mosaics are perfect reminders of the importance of collaboration and of the iterative process looping together to make something wonderful for a grander audience to enjoy."*

**Figure 5. Visual Components of Cathy's Memory Aid for Senior B Data (small and large mosaics)**

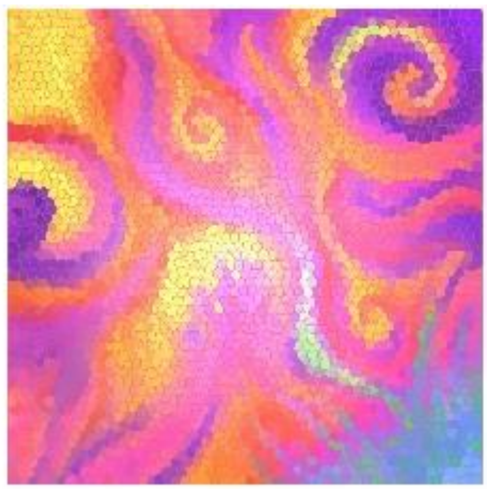


**Figure 6. Visual Components of Cathy's Memory Aid for Her Data (small & large mosaics)**

The textual component of Cathy's memory aid, which helps put all the pieces together, is presented in Figure 7.

**Definition of design:**

*People, process, usability:*

People = orchestra, pianist, performer. Mosaic tiles each person = 1 tile.

Process = song's looping qualities and crescendo.

Usability = preformed to an audience (user) and they absorb the song (that doesn't have lyrics) and make their own interpretation of it.

**Figure 7. Textual Component of Cathy's Memory Aid**

*Karl's Design Process Representations (DB1 and DB2) and Memory Aid* *

Karl chose to visualize design processes by writing a computer program to automatically generate color coded squares representing each design activity to form a grid. He wanted to show how the overall design process evolves from the beginning to the end and initially used red colors to represent activities he thought normally occur early in the design process, white for activities normally occurring in the middle of the process, and blue for activities normally occurring at the end of the process.

Figure 8 provides an example, illustrating the design process of a fourth-year undergraduate student (Senior B). Figure 9 shows his own design process from DB2, in which he reversed the colors (i.e., from blue to red instead of red to blue). He chose the album cover of Abbey Road by the Beatles to overlay the tiles because the album reminded him of the importance of 1) using diverse techniques, 2) teamwork, and 3) taking all stakeholders into account when doing design, as he describes below:

> *"It contains many musical styles that come together to form an interesting and unique blend of music…This reminds me of the importance of using many techniques while going through the design process. This was also the last album the Beatles created as a team…This reminds me of the importance of teamwork … One of the greatest quotes from music ever recorded can be found on this album: "And in the end, the love you take is equal to the love you make." This reminds me that I need to take into consideration all stakeholders as I go through the design process."*

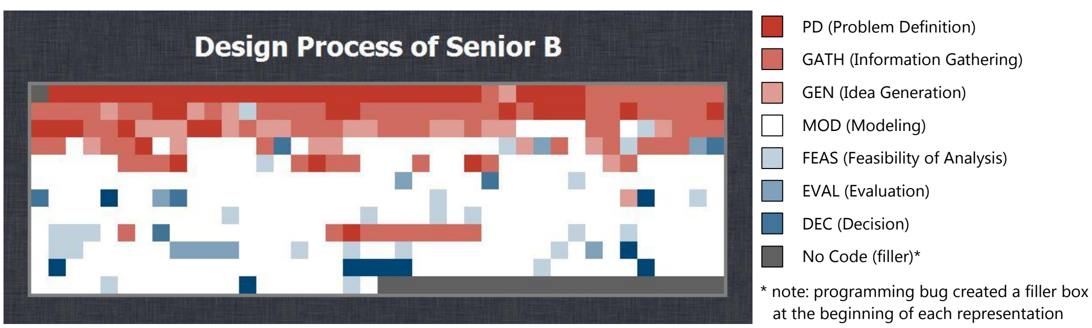



**Figure 8. Karl's Representation of Senior B's Design Process from DB1**

The memory aid Karl created was a game spinner (modified from a popular board game) with labels for selected design process activity. Depicted in Figure 10, it was intended to be kept on a desk as a reminder of one's personal design process so that when "stuck", one could use the spinner to find activities to get "un-stuck". The design activities chosen for the spinner were research, ideation, prototyping, testing, and perspective. In his chapter of the technical report, Karl defined each of these activities as follows: "Research" might entail user research, competitive analysis, or other problem space research, which helps one think about the design problem in a different way, or to identify further needs that should be addressed. "Ideation" is an obvious choice for getting "un- stuck", as there are many ideation activities that can get the creative design juices flowing, such as brainstorming. "Prototyping" is sometimes helpful, as

* Portions of this sub-section are adapted or excerpted from [1].


**Figure 9. Karl's Representation of His Own Design Process from DB2**

simply building or creating something (anything) can get one's mind back to designing. "Testing," which naturally comes after prototyping, is sometimes helpful to do at unexpected times in the design process because one can gain new insights by retesting previous iterations, or even just reviewing previous test results. Finally, "Perspective" is distinct from research: rather than being centered around the problem space specifically, it provides a chance to broaden one's thought processes by changing one's own perspective, e.g., through art or music to inspire new ways of thinking.

Karl also provided the following insight into his thinking behind the strategic choice of a spinner (shown in Figure 10):

> *"the circular form of the spinner and its ability to spin around and around reminds me that design is an iterative process, and that the different design activities should be done multiple times to produce a quality product. Secondly, the randomness that is introduced by the spinner reminds me that the activities don't always have to be followed in sequence. Oftentimes it is helpful to do a step "out of order". It reminds me to think of each of these activities as a tool that can be used at any time, and not just a step in a linear process."*


**Figure 10. Karl's Memory Aid**

*Tim's Design Process Representations (DB1 and DB2) and Memory Aid*

Tim chose to visualize design processes using computer-generated, color-coded timelines that emulated the CPU Usage History graph on a computer. The objective of this representation was "to provide an accurate representation of the data in real-time." These timelines were created using a custom Java program that manipulated the data so that design activities receiving the primary focus at any given time were drawn at the top of the graph while other, shorter duration and overlapping activities appeared as peaks reaching up from the bottom. For example, note the teal/green colored line for Modeling that appears across most of the top of the graph in Figure 11 (since Modeling was Senior B's dominant activity), while other activities spiked up below it, occasionally pulling the Modeling line down as they competed for precedence. Tim wrote that he was essentially capturing a snapshot of the brain at a particular moment, with each point on the line representing a one second snapshot of the brain. He also wrote the following of the representation and the multi-tasking ability of the human brain:

> *"One thing I wanted to convey was the idea that brains don't always think in binary. The brain is a multi-functional system, it can do several things at once. I know that in my own design process I tend to switch very fast between different design steps but still retain previous memory of what I was doing before and can quickly pick up what I was doing before even with a slight interruption of another design step."*

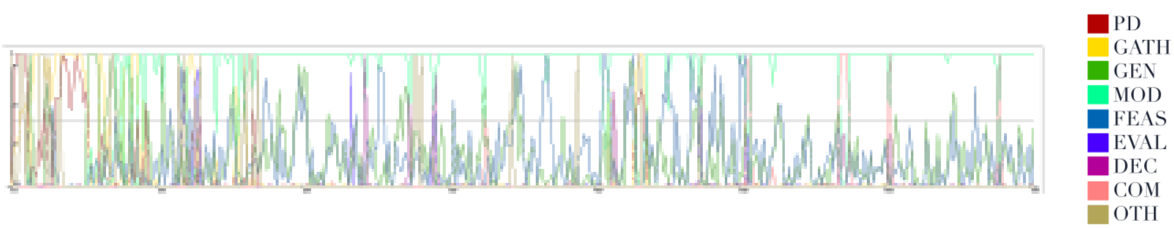



**Figure 11. Tim's Representation of Senior B's Design Process from DB1**

For DB2, Tim used an approach similar to the one he used for DB1, this time borrowing ideas from Student Leah's DB1 representation to make it more visually pleasing. Specifically, he indicated borrowing her color scheme and her idea for area-based representation (i.e., the more area one color takes, the more time spent on that particular activity). The result is shown in Figure 12.

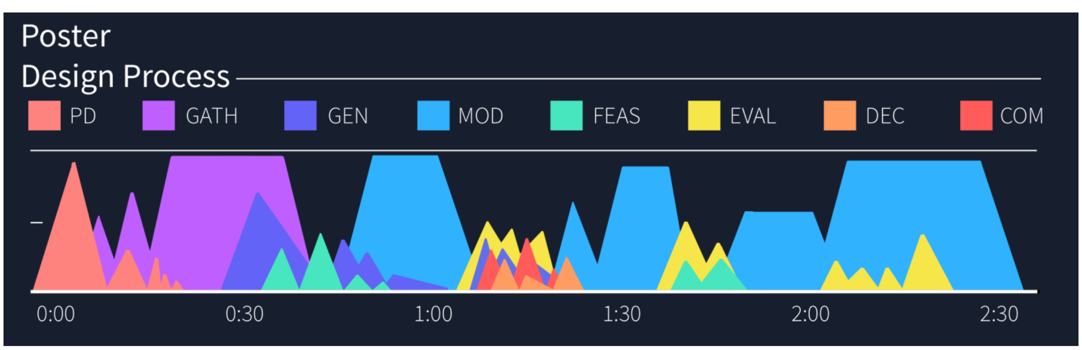



**Figure 12. Tim's Representation of Own Design Process from DB2**

The memory aid Tim created was a computer-generated symbol or icon that was intended to be displayed somewhere conspicuous, e.g., by printing it out on a sticker or setting it as the wallpaper on his mobile phone. The symbol, shown in Figure 13, reflected his two main takeaways from the course: the iterative aspect of design and the Ideal Design Envelope. He wrote that "two arrows going around in a circle, like a refresh button" were inspired by a spiral and indicated iteration. He also pointed out that the circular shape was roughly similar to that of Ideal Design Envelope, and that to make this more apparent, he added the colored lines to represent the various design activities. The colors matched the color code from his DB2 representation (see Figure 12), and the height of each color band indicated how much time should ideally be spent in that activity.

**Figure 13. Graphic of Tim's Memory Aid**

*Leah's Design Process Representations (DB1 and DB2) and Memory Aid*

Leah chose to visualize design processes with computer-generated bubble-charts, like that shown in Figure 14. A stated objective for this representation was to "deliver explicit figures that easily explain what [they are]." Each design activity was color coded and displayed in its own column, with a vertical axis indicating the sequence of time. The size of each circle represented the amount of time spent in that particular activity at that particular time in the design session. For DB2, she represented her own design process in the same way, as shown in Figure 15. These representations highlight both the most prevalent design activities (in terms of length of time the designer was engaged in that activity), as well as when during the design session the largest blocks of time were used for each activity. For example, Figure 14 shows that Modeling was the most prevalent activity and that, while Evaluation occurred a number of times throughout the session, the largest block of time spent on Evaluation occurred around the 2 hour mark.

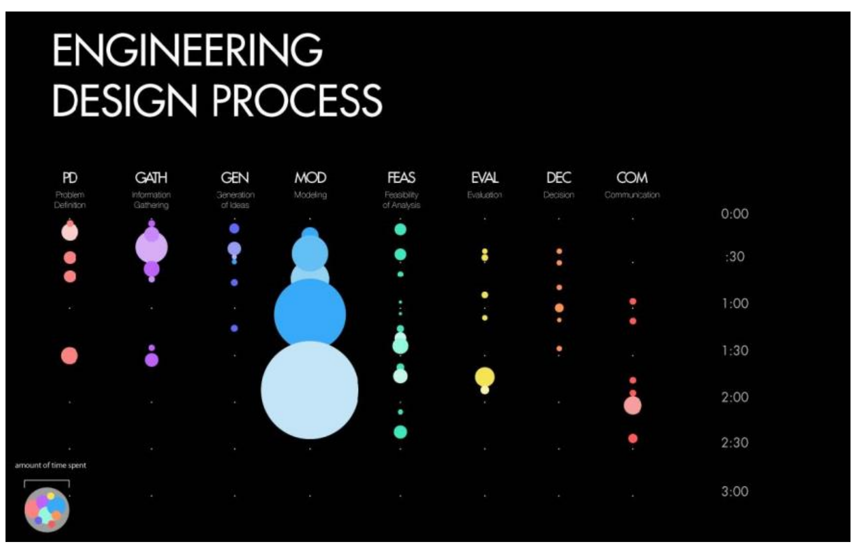



**Figure 14. Leah's Representation of Senior B's Design Process from DB1**

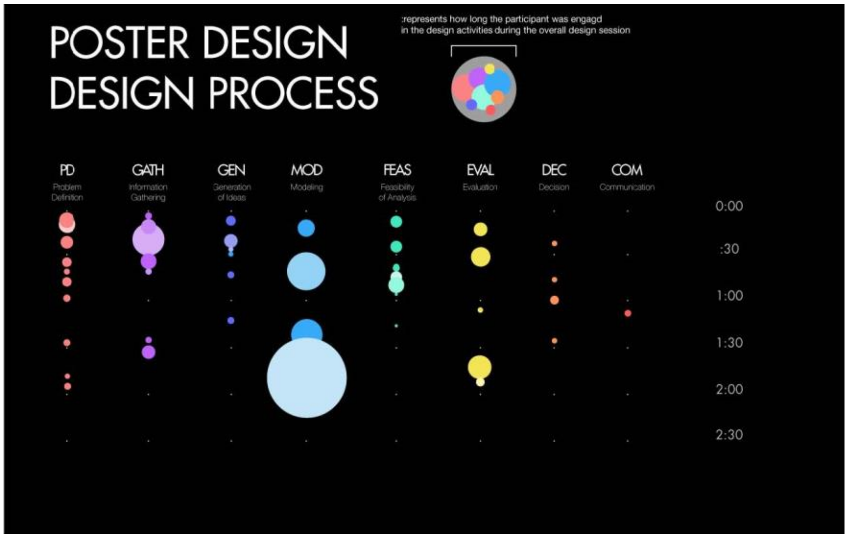



**Figure 15. Leah's Representation of Own Design Process from DB2**

The memory aid that Leah created was a hand-drawn, graphical representation of design process data overlaid with the Ideal Project Envelope. This was drawn on an index card, as shown in Figure 16, and portrays an approximation of Senior B's design process data with different colors for most of the design activities from Figure 1 in the Introduction section above. Her rationale for using an index card was practical and pragmatic: "because every-one has index cards on their desks and it is very easy to get. Also, the shape of the index card …" facilitated drawing the Ideal Project Envelope or cascade pattern, which shows "that significant time is spent in [the] early design processing stage (top four lines), such as problem definition, gathering information, etc. and consid-ering the larger context of the problem."

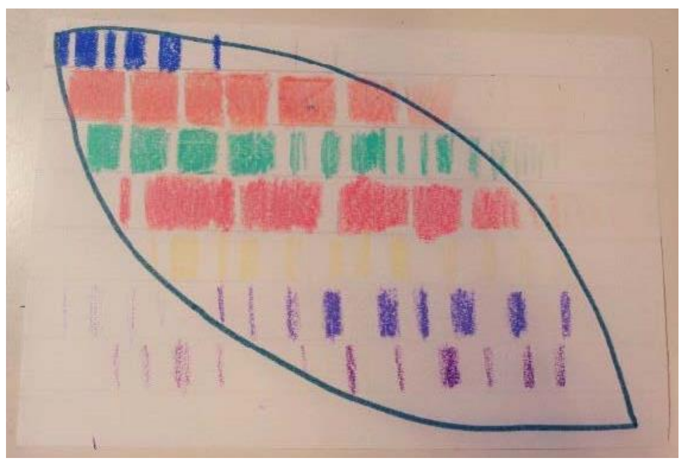


**Figure 16. Graphic of Leah's Memory Aid**

*Scott's Design Process Representations (DB1 and DB2) and Memory Aid*

For the first design brief exercise (DB1), Scott created a physical three-dimensional model to represent design processes, as shown in Figure 17. The model was made with paper boxes of different colors, patterns, and sizes to form a three-dimensional bar graph. The colors represented each of the different design stages: blue for Problem Scoping, red for Developing Alternative Solutions, and yellow for Project Realization. Each design activity was represented by a distinct pattern and also labeled for clarity. The heights of the boxes indicated the number of occurrences for each design activity, with the smallest boxes representing one instance, the largest box representing 100 instances, and the intermediate sizes representing 5, 10, and 20 instances, respectively. The largest boxes were placed in the back of each design activity for ease of visibility. The model was organized from left to right in increasing order of total number of occurrences for each design activity.

For the second design brief exercise (DB2), Scott used a different approach, this time making a flip-book of his design process. As shown in Figure 18, the representation is based on photographs that represented the broad activities in which he found himself engaged: Determining Parameters, Researching, Writing, Drawing, and Checking Work. “Determining Parameters” was symbolized by a photo of a speed limit sign, which represented understanding the rules in order to star the project off on the right foot. “Researching” was symbolized by a photo of books on a desk in a library, which represented the process of gathering the information needed to understand and execute the design. “Writing” was symbolized by a photo of a fountain pen writing on paper, which illustrated the importance of not just thinking, but of actually putting ideas down on paper. “Drawing” was symbolized by a picture of two hands drawing each other, which signified the process of modeling or mocking up a design in order to give reality and substance to an idea. Finally, “Checking Work” was symbolized by a photo of a checklist (i.e., a pencil checking off boxes on paper), which represented the process of assessing what one has created to see if it met the design parameters. In the word of Scott, the objective of the flip book was to allow the viewer:

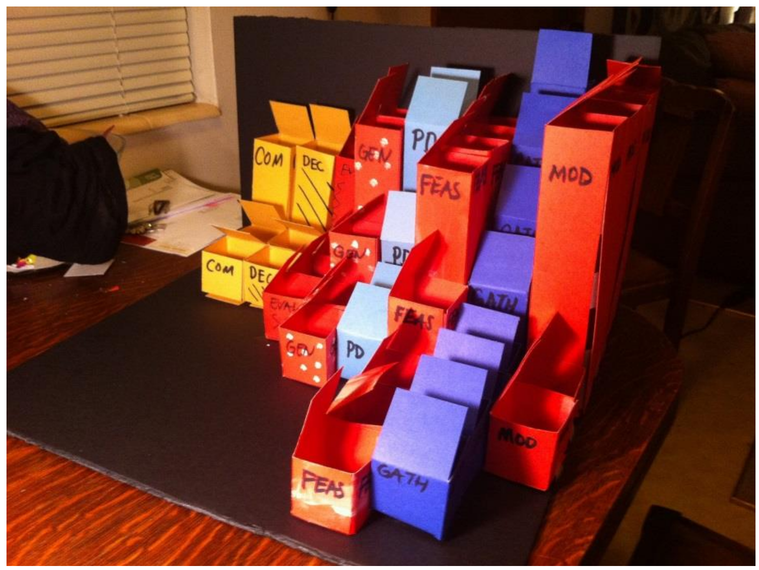


**Figure 17. Scott’s Representation of Expert B’s Design Process from DB1**

**Figure 18. Scott’s Representation of Own Design Process from DB2**

*"… to intake visual information sequentially, through the use of correlating images in order of occurrence. This allows for the viewer to experience the overwhelming effect of the most frequent activity, [… understand] visually the activities occurring least, as well as [gain] a sense of time for when these activities take place in comparison to others."*

The memory aid that Scott created was a graphical icon created on a computer. As shown in Figure 19, the icon is a three-by-three grid depicting nine different symbols each representing a different design activity as identified by Scott's personal definition of the design process. In the technical report, Scott explained that the memory aid serves to summarize his personal design process and illustrates the cyclical and iterative nature of design:

*"It serves to represent the basic procedures and categories beneficial for developing a strong and well thought out design. The steps should serve as a cyclical representation; should a designer get stuck in a certain task, they should be able to review the preceding and following tasks to better understand what they may need to accomplish in order to proceed. While starting at step one is suggested, the beginning task [may] vary dependent on the design task itself, and should serve as a general framework for designing."*

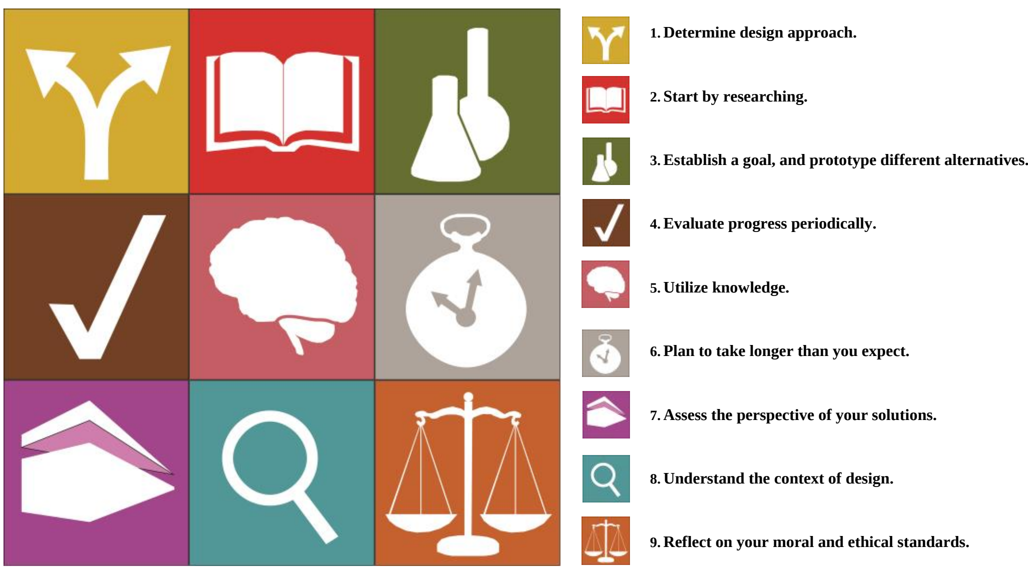



**Figure 19. Graphic of Scott's Memory Aid**

*Anne's Design Process Representations (DB1 and DB2) and Memory Aid*

Anne chose to visualize design processes using computer-generated, color-coded timelines. Essentially, this involved compressing the given design process timeline data into a single, color-coded timeline in a way that highlighted important lessons learned about designing. To create these representations, Anne first aggregated individual design activities into one of the three corresponding design stages (i.e., problem scoping, developing alternative solutions, and project realization—see Figure 1). These were then color coded with primary colors and then merged in to a single timeline. Any overlapping activities were represented by their corresponding overlapping color, as shows in the Venn diagram in Figure 20 which illustrates the design process of an experienced practicing professional (Expert B). Figure 21 shows Anne's own design process from DB2. The stated goals of this representation approach were to make the following more visible:

1) the use of problem scoping (represented by the teal, as well as blue and green colors)
2) the cascade pattern of transitions between design activities (highlighting the importance of varying one's design activities, e.g., so as to not get stuck)
3) the Ideal Project Envelope (see Figure 2)

With the data represented in this manner, one can quickly see the dominant colors (design stages) and the relative frequencies of transitions.

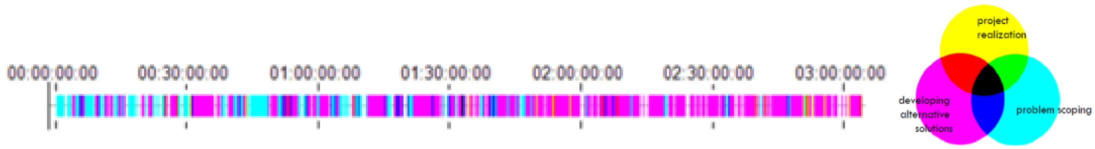



**Figure 20. Anne's Representation of Expert B's Design Process from DB1**

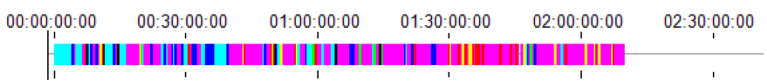



**Figure 21. Anne's Representation of Own Design Process from DB2**

The memory aid that Anne created was a mobile or kinetic sculpture made using paper cutouts and connected together with transparent mono-filament "fishing" line. As shown in Figure 22, the top of the mobile (which hangs from the ceiling) is made of three pieces of translucent paper to form a Venn diagram that represents the three overlapping stages of design. Hanging from the Venn diagram is a white, cascade-shaped piece representing the Ideal Project Envelope, which, in turn, supports dozens of small, colored circles that represent units of time spent in particular design stages.

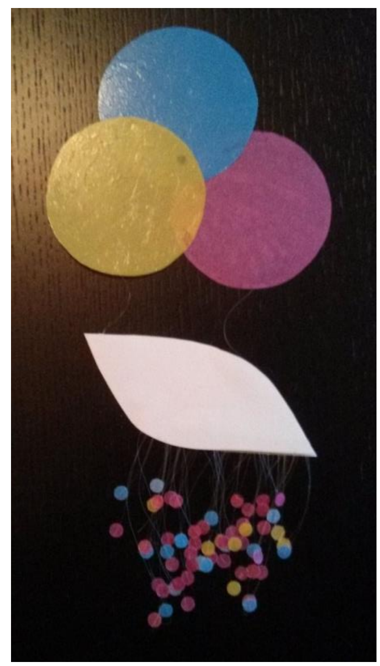


**Figure 22. Graphic of Anne's Memory Aid**

*James's Design Process Representations (DB1 and DB2) and Memory Aid*

For the first design brief exercise (DB1), James chose to visualize design processes with a simple line graph that depicts increases in usage of each design activity over the total time taken to complete the design task. Figure 23 shows the result for Expert B, which received a quality score of 0.55 ("55% Success"). The vertical axis in the chart (labeled "Method Usage") shows the number of times each design activity was coded in the data. The horizontal axis (labeled "% Completed") represents the time dimension. This representation gives a clear indication of the prevalence of each design activity, as well as when each was employed over the course of the design task.

For the second design brief exercise (DB2), James used a completely different approach, making a poster of his design process. As shown in Figure 24, the representation is a color coded bubble chart, in which bubble color represents the various design activities and bubble size represents the amount of time spent on that activity. The bubbles are arranged from top to bottom in the sequence of time, and three design stages (Research, Design, and Iteration & Re-design) are indicated across the background. The design stages and activities differ from those presented in Figure 1 because they were derived retrospectively from the overarching needs James saw unfolding in his design process. For example, he defined his Research stage based on three activities: problem definition (figuring out, reading the brief to understand what was being asked), discovery (opening up anything and everything he could find to research the topic associated with the problem definition), and gathering (pulling materials from the discovery activity that may be useful within the design). The representation of Figure 24 was intended to be a snapshot of his design process from beginning to end that reflected the way "everything seemed to happen at once" within each phase of the design due to the scattered nature of his methodology.

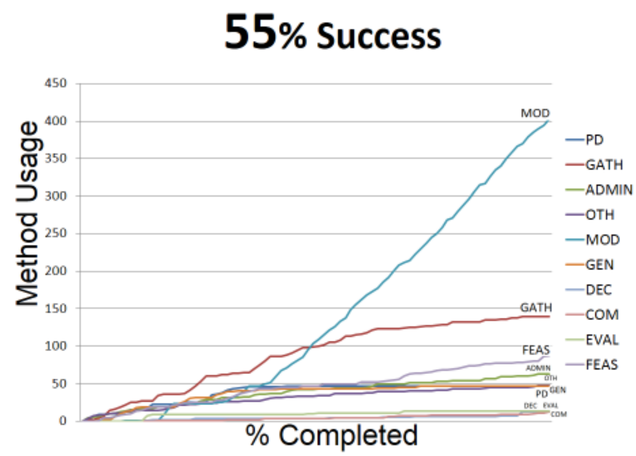



**Figure 23. James's Representation of Senior B's Design Process from DB1**

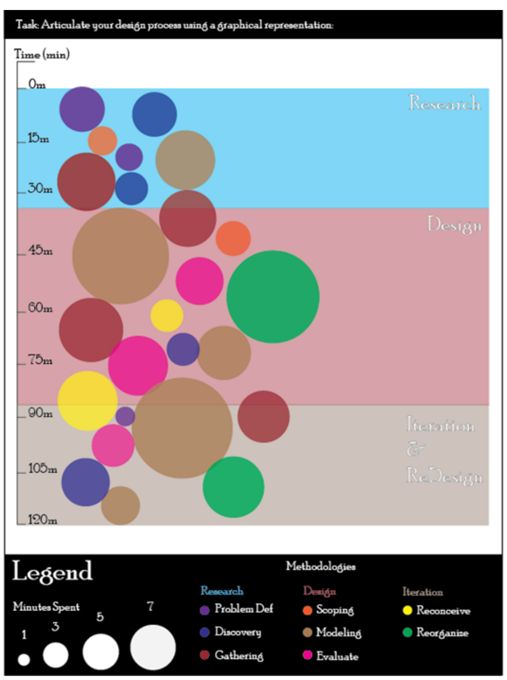



**Figure 24. James's Representation of Own Design Process from DB2**

As shown in Figure 25, the memory aid that James created was a verbal/textual mantra that ties together his philosophy of design: "The harder I work, the luckier I get." The first half of the mantra reminds him to consider different methodologies and multiple perspectives into account to make improvements. The second half of the mantra is a reference to the famous quote by Louis Pasteur: "Chance favors the prepared mind" that was discussed at multiple points in class during the quarter. This reminds him to work hard so that he is prepared to take advantage of opportunities when they arise.

*"The harder I work, the luckier I get."*

**Figure 25. Text of James's Memory Aid**

*Beth's Design Process Representations (DB1 and DB2) and Memory Aid*

Beth chose to visualize design processes for DB1 using a computer-generated multi-media movie. To create this movie, Beth started with a version of the data that had been translated into "music" (e.g., by assigning a particular tone to each design activity and playing the timeline sequentially at high speed). She played the file through music visualization software and recorded the result, a screen-shot for which is shown in Figure 26. Using both sound and moving boxes of varying sizes and colors, the movie depicted periods of multi-colored, cacophonic activity separated by periods of relative calm. This approach to representing design processes emphasized the dynamic nature of design.

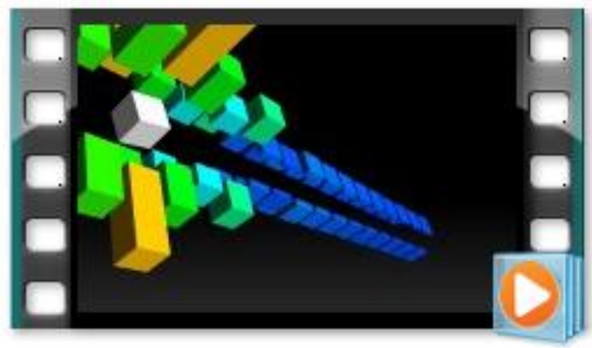


**Figure 26. Beth's Representation of Senior B's Design Process from DB1**

For DB2, Beth again used a multi-media approach, but this time using timed snapshots of herself working on the design task. The resulting stop-motion animation was then set to calm, classical music being played on a piano. A screen-shot of the result is given in Figure 27, which shows her work-space with her laptop computer, papers, and a cup of coffee. She reported that watching the animation was:

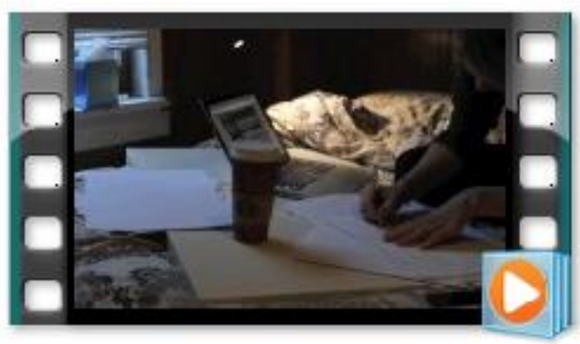


**Figure 27. Beth's Representation of Own Design Process from DB2**

> *"... a great way for me to gain a deeper insight into my creative process. What stood out to me most was how I spent a big chunk of time researching in the beginning, understanding the problem and what the task would entail, but then throughout my "designing time" I would often iterate going back and looking things up and then back again to designing.*

The memory aid Beth created was based on a quotation that she found both memorable and inspiring, which she then used as a mnemonic and mapped it to what she felt she needed to remember "in order to be a well-rounded designer…and most importantly, a well-rounded human-being." As shown in Figure 28, the quotation was "The problem with reality is the lack of background music," and the take-aways (with mnemonic cues in bold font) were as follows: "Understand the **Problem**," "**Research** who the users are," "**Listen** and **Learn**," "**Brainstorm**, make, iterate," and "**eMpathy**."

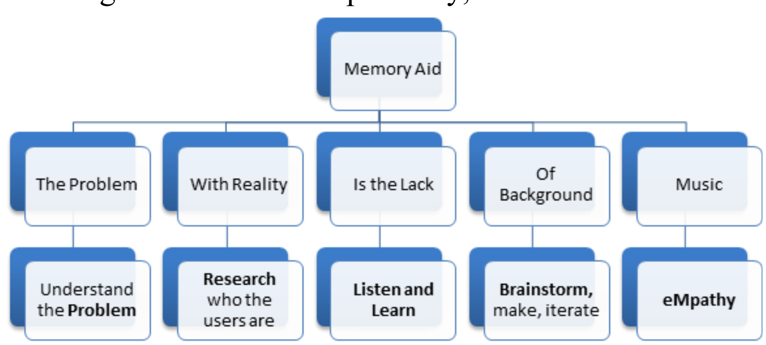



**Figure 28. Graphic of Beth's Memory Aid**

## Mapping Student Representations to Design Timeline Concepts

In order to understand if the design timeline concepts that were presented to students and used as advance organizers had an impact on student work, one author coded the student work to determine whether the design timeline concepts appeared in the student representations. The specific codes were derived from empirical findings from research in design processes, and are shown in the first column of Tables 2 and 3. The categories include the specific design activities and design stages presented earlier in Figure 1, as well as research findings that can be described at both the design activity and design stage level [9, 10]. Materials analyzed included the student representations themselves, as well as text from the documents that accompanied their representations for DB1, DB2 and the Memory Aid, and finally the students' verbal descriptions of their final memory aid as captured in a video and instructor's notes in the last class period. A sample of the coded transcripts were examined independently by a second author, all questions were discussed and final code applications were determined.

**Table 2: Design Timeline Concepts as Reflected in Student Work (by Student)**

| Design Element Included in Assignments | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Student: | Cathy | | | Karl | | | Leah | | | Tim | | | Scott | | | Anne | | | James | | | Beth | | |
| Assignment: | DB1 | DB2 | Mem Aid | DB1 | DB2 | Mem Aid | DB1 | DB2 | Mem Aid | DB1 | DB2 | Mem Aid | DB1 | DB2 | Mem Aid | DB1 | DB2 | Mem Aid | DB1 | DB2 | Mem Aid | DB1 | DB2 | Mem Aid |
| **Design Activities** | | | | | | | | | | | | | | | | | | | | | | | | |
| Problem Definition | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | ■ | ■ | | | ■ | ■ |
| Information Gathering | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | | | ■ | ■ |
| Generate Ideas | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | ■ | ■ | | | | ■ |
| Modeling | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | ■ | ■ | | | ■ | ■ |
| Feasibility Analysis | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | ■ | | | | | |
| Evaluation | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | ■ | ■ | | | | |
| Decision | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | ■ | | | | | |
| Communication | ■ | ■ | ■ | | ■ | | ■ | ■ | | ■ | ■ | ■ | ■ | | | | | | ■ | | | | | |
| **Design Stages** | | | | | | | | | | | | | | | | | | | | | | | | |
| Problem scoping | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | | | | ■ | | | ■ | ■ | ■ | | ■ | | | | |
| Developing Alternative Solutions | ■ | ■ | ■ | ■ | ■ | | | ■ | | | | | ■ | | | ■ | ■ | ■ | | ■ | | | | |
| Project Realization | ■ | ■ | ■ | ■ | ■ | | | ■ | | | | | ■ | | | ■ | ■ | ■ | | | | | | |
| **Research Findings - Design Activity Level** | | | | | | | | | | | | | | | | | | | | | | | | |
| Information Gathering - more | ■ | ■ | ■ | | | ■ | | | | | | | | | | | | | | | | | ■ | |
| Information Gathering - distributed throughout | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | ■ | |
| Modeling is important | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | |
| Transitions - many | | | | ■ | ■ | | | | | ■ | | | | | | | | | | | | | | |
| Iteration is important | ■ | ■ | ■ | | | ■ | | | | | | ■ | | ■ | ■ | | | ■ | | ■ | | | ■ | ■ |
| **Research Findings - Design Stage Level** | | | | | | | | | | | | | | | | | | | | | | | | |
| Problem Scoping - more time | | | | | | | | | ■ | | | | | | | | | | | | | | | |
| Problem Scoping - more effective | | | | | | | | | | | | | | | | ■ | ■ | | | | | | | |
| Problem Scoping - early in the process | | | | | | | | | ■ | | | | | | | | | | | | | | ■ | |
| Include Project Realization activities | | | | | | | | | | | | | | | | | | | | | | | | |
| **Research Findings - General** | | | | | | | | | | | | | | | | | | | | | | | | |
| Longer amount of time | ■ | ■ | ■ | ■ | ■ | | | | ■ | | | ■ | | | | ■ | ■ | | ■ | | | | ■ | |
| Cover breadth of activities | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | | | | |
| Repetition of activities | | | | | | ■ | | | | | | | | ■ | | | | | | ■ | | | | |
| Cascade shape/Ideal Project Envelope | ■ | ■ | ■ | ■ | ■ | | | | ■ | | | ■ | | | | ■ | ■ | ■ | | | | | | |
| Design process is non-linear | ■ | ■ | ■ | | | ■ | | | | | | | | | | | | | | | | | | |
| Design Process is Complex | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | ■ | | |
| Redefine problem | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | | |
| Total number of codes per assignment: | 21 | 21 | 21 | 15 | 16 | 10 | 8 | 11 | 12 | 9 | 8 | 11 | 11 | 7 | 6 | 8 | 8 | 6 | 10 | 10 | 0 | 1 | 8 | 5 |
| Total number of codes across all 3 assignments: | 63 | | | 41 | | | 31 | | | 28 | | | 24 | | | 22 | | | 20 | | | 14 | | |

The results of this mapping are displayed in Tables 2 and 3. Table 2 presents the mapping for each of the three tasks for each student, and Table 3 presents the same coding but ordered by the mapping of each student for each of the three tasks. Each mapping affords different types of observations.

The student work presented in Table 2 is ordered from left to right with the left side including the highest number of design timeline concepts and the right side including the fewest concepts. This order is used as a way to order the work for description, not as judgment on quality of the student representations. Other mappings and organizations would yield equally interesting but totally different ordering for the student work. For example, if the number of concepts incorporated into the representations that came from other parts of the course (or maybe previous student experiences based on self-reports) and were *not* linked to the design timeline concepts were used, the order would be quite different. This would be an interesting idea to explore for future research with these representations, perhaps yielding some insights into what kinds of concepts were scaffolded into student representations through the student execution of these tasks.

Looking at the three representations over time suggests that each student's trajectory of learning was very compelling. Although there are only eight students, we see quite a bit of variation of trajectories across the set. By examining both Table 1, with the student representations by row, as well as Table 2 with the results of the coding by column, one can describe these trajectories. For example, in Cathy's representation, she initially chose to incorporate all the design activities and stages along with a set of the larger research findings in DB1, and she kept those elements engaged in both DB2 and her Memory Aid. In contrast, James included the full set of design activities plus two other research findings in his DB1 which was a graphical representation of the data that produced the timelines. As he moved to a more abstract representation for DB2, he shifted the timeline concepts included in his work. Finally, for James' Memory Aid, he chose to use a mantra: "The harder I work, the luckier I get." He related his mantra to a quote from Louis Pasteur that we discussed throughout the course: "Chance favors the prepared mind." While this quote is not directly tied to the design concepts he included in his DB1 and DB2, it certainly conveyed that he had put considerable thought into choosing his top take-away from the course.

Through additional observations afforded by Table 1, we note that Scott changed the media he used for each task, moving from a 3D bar chart representation, to a flip book to a graphic design. Tim created three graphic designs, and challenged himself each time to get more abstract. His DB1 representation presented each data point literally, his DB2 showed blocks of design activities represented by color, and his Memory Aid was an abstract symbol that included color. Karl, Leah and Beth each built their DB2 representation of their personal design process as an extension of their DB1 representation, and then moved to a very different representation for their Memory Aid. Karl moved from a graphic table representation to an interactive game spinner, Leah moved from a graphical bubble representation to a quick-reference index card, and Beth moved from video representations to an interpretation of a quote that was meaningful to her. Finally, Anne started her DB1 representation at the more abstract "Design Stage" level rather than at the detailed "Design Activity" level. She also built her DB2 representation on her DB1 representation, and kept her focus on the Design Stage level as she got more parsimonious in the design elements she included in the physical representation of her Memory Aid which was a mobile.

Other observations are afforded by the examination of Table 3 that presents the student work ordered by task. With a very broad brush, this organization allows the reader to see that the design timeline concepts are incorporated by the students into all three representations, with the most concepts appearing in DB1 and the least in the Memory Aid. The fact that the concepts still appear in DB2 and the Memory Aid provides an "existence proof" level of evidence that the advance organizer concepts are useful to the students. By examining the concepts that appear across the students in their Memory Aid representation, one can see the concepts that proved to be the most compelling. The top two from the research findings include iteration (represented by Karl's spinner, arrows in Tim's icon, Scott's icon with multiple entry points, backward swirls in Cathy's painting, disks hanging on Anne's mobile, and "Brainstorm, make, iterate" in Beth's mnemonic) and the cascade shape (middle part of Anne's mobile, shape drawn on Leah's 3x5 card, direction of Cathy's painting going from upper left to lower right, circular shape of Tim's icon). Specific design activities that resonated for most students included problem definition, information gathering, generating ideas and modeling. Looking at Table 3, it is also notable that, as a group, the students seemed to pair-down the number of concepts included from one assignment to the next. An interesting exception to this is that only one student, Cathy, included "iteration" in DB1, but half of students included "iteration" in DB2 and all but two in their Memory Aid.

**Table 3: Design Timeline Concepts as Reflected in Student Work (by Task)**

| Design Element Included in Assignments | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Assignment: | Design Brief 1 | | | | | | | | Design Brief 2 | | | | | | | | Memory Aid | | | | | | | |
| Student: | Cathy | Karl | Leah | Tim | Scott | Anne | James | Beth | Cathy | Karl | Leah | Tim | Scott | Anne | James | Beth | Cathy | Karl | Leah | Tim | Scott | Anne | James | Beth |
| **Design Activities** | | | | | | | | | | | | | | | | | | | | | | | | |
| Problem Definition | ■ | ■ | ■ | ■ | ■ | | ■ | | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | ■ |
| Information Gathering | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | ■ |
| Generate Ideas | ■ | ■ | ■ | ■ | ■ | | ■ | | ■ | ■ | ■ | ■ | ■ | | ■ | | ■ | ■ | ■ | ■ | ■ | | | ■ |
| Modeling | ■ | ■ | ■ | ■ | ■ | | ■ | | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | ■ |
| Feasibility Analysis | ■ | ■ | ■ | ■ | ■ | | ■ | | ■ | ■ | ■ | ■ | | | | | ■ | | ■ | ■ | | | | |
| Evaluation | ■ | ■ | ■ | ■ | ■ | | ■ | | ■ | ■ | ■ | ■ | ■ | | ■ | | ■ | ■ | ■ | ■ | ■ | | | |
| Decision | ■ | ■ | ■ | ■ | ■ | | ■ | | ■ | ■ | ■ | ■ | | | | | ■ | | ■ | ■ | | | | |
| Communication | ■ | | ■ | ■ | ■ | | ■ | | ■ | ■ | ■ | ■ | | | | | ■ | | | ■ | | | | |
| **Design Stages** | | | | | | | | | | | | | | | | | | | | | | | | |
| Problem scoping | ■ | ■ | | | ■ | ■ | | | ■ | ■ | ■ | | | ■ | ■ | | ■ | ■ | ■ | | | ■ | | |
| Developing Alternative Solutions | ■ | ■ | | | ■ | ■ | | | ■ | ■ | ■ | | | ■ | ■ | | ■ | | | | | ■ | | |
| Project Realization | ■ | ■ | | | ■ | ■ | | | ■ | ■ | ■ | | | ■ | | | ■ | | | | | ■ | | |
| **Research Findings - Design Activity Level** | | | | | | | | | | | | | | | | | | | | | | | | |
| Information Gathering - more | ■ | | | | | | | | ■ | | | | | | | ■ | ■ | ■ | | | | | | |
| Information Gathering - distributed throughout | ■ | | | | | | | | ■ | | | | | | | ■ | ■ | | | | | | | |
| Modeling is important | ■ | ■ | | | | | | | ■ | ■ | | | | | | | ■ | | | | | | | |
| Transitions - many | | ■ | | ■ | | | | | | ■ | | | | | | | | | | | | | | |
| Iteration is important | ■ | | | | | | | | ■ | | | | ■ | | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | | ■ |
| **Research Findings - Design Stage Level** | | | | | | | | | | | | | | | | | | | | | | | | |
| Problem Scoping - more time | | | | | | | | | | | | | | | | | | | ■ | | | | | |
| Problem Scoping - more effective | | | | | | ■ | | | | | | | | ■ | | | | | | | | | | |
| Problem Scoping - early in the process | | | | | | | | | | | | | | | | ■ | | | ■ | | | | | |
| Include Project Realization activities | | | | | | | | | | | | | | | | | | | | | | | | |
| **Research Findings - General** | | | | | | | | | | | | | | | | | | | | | | | | |
| Longer amount of time | ■ | ■ | | | | ■ | ■ | | ■ | ■ | | | | ■ | | ■ | ■ | | ■ | ■ | | | | |
| Cover breadth of activities | ■ | ■ | | | | ■ | ■ | | ■ | ■ | | | | ■ | ■ | | ■ | | | | | ■ | | |
| Repetition of activities | | | | | | | | | | | | | ■ | | ■ | | | ■ | | | | | | |
| Cascade shape/Ideal Project Envelope | ■ | ■ | | | | ■ | | | ■ | ■ | | | | ■ | | | ■ | | ■ | ■ | | ■ | | |
| Design process is non-linear | ■ | | | | | | | | ■ | | | | | | | | ■ | ■ | | | | | | |
| Design Process is Complex | ■ | | | | | | | ■ | ■ | | | | | | | | ■ | | | | | | | |
| Redefine problem | ■ | | | | | | | | ■ | | | | | | | | ■ | | | | | | | |
| Total number of codes per student: | 21 | 15 | 8 | 9 | 11 | 8 | 10 | 1 | 21 | 16 | 11 | 8 | 7 | 8 | 10 | 8 | 21 | 10 | 12 | 11 | 6 | 6 | 0 | 5 |
| Total number of codes across all 8 students: | 83 | | | | | | | | 89 | | | | | | | | 71 | | | | | | | |

## Discussion

In this paper, our goal has been to show how a group of students responded to an innovative opportunity to represent design processes through three specific activities: Design Brief 1 (DB1), Design Brief 2 (DB2) and creation of a Memory Aid. The previous pages serve to emphasize the immense creativity and engagement of the students in these tasks. This engagement is particularly noteworthy because the students received only a small amount of non-graded credit for their participation.

The significance of the student work in this paper can be understood by connecting to various theoretical perspectives on the conditions that lead to learning. For example, time on task is understood as a predictive variable for learning [16], and nearly all the representations shown in this paper clearly required significant effort from the students. Also, re-representing, or translating information is known to be associated with learning, and was clearly evidenced by the student work. Additionally, if one examines what the students were able to accomplish with the knowledge they gained from the initial timeline representations and discussions, one would conclude (e.g., based on to Bloom's Taxonomy of learning objectives - see [17-19]) that these eight students were not only applying knowledge, they were making judgments, synthesizing, and creating, all of which require in-depth understanding of the concept of design.

Finally, the mapping of student work to the design timeline concepts that were used as an advance organizer provides one possible explanation for the number of concepts that remained "sticky" for the students when they developed their final representation for the course (i.e., the memory aid).

While our investigation into the learning that was afforded by this set of tasks has provided useful insights into the benefit of using these tasks with engineering students, it has also opened the door to more questions. Follow-up research might explore the specific nature of the representation efforts shown here, i.e., that of turning a process into an artistic representation. We would also like to investigate the student responses to these tasks in detail using verbal protocol analysis so we could better understand the specific activities the students are engaging in while they create these representations. Verbal protocol analysis might also help us to understand more about the depth and breadth of the knowledge that a memory aid is intended to help a student to recall. As was noted earlier, in the final memory aid assignment, fewer concepts were represented by the students overall. However, our belief is that the memory aids were designed as succinct "unique" keys that would unlock a student's rich conceptual understanding of design processes. We would also like to develop some short instruments that would enable us to assess student learning. Finally, we would like to broaden the study by gathering responses of engineering students from multiple engineering disciplines engaging with these tasks.

**Implications for Educational Settings**

How might the tasks described in this paper be used in undergraduate engineering curricula? Most engineering programs have a final culminating capstone design project that is large in scope. Some programs include design projects as part of a freshman course, and the opportunity for students to experience design in the middle two years is infrequent. We have heard from students that the learning experiences in this course were transformative. Students who were in the beginning of their program (juniors) said that this course provided an understanding of design processes that was a useful starting point from which to build for the rest of the courses in their major. We also heard from students as they were graduating that they were including their design representations from this class in the portfolio they were preparing to show prospective employers during an interview.

The time that the students invested in these three tasks is modest when compared to the time students spend in a capstone design course. The tasks could be tailored to fit into any engineering program by creating a discipline specific design problem for DB2. And finally, the tasks are very approachable and could be incorporated into the student learning experience at any point in the curriculum.

At the end of each class the students filled out reflection sheets where they were asked to describe what aspects of the class was rewarding, caused frustration, created a surprise or "aha" moment. They also sketched something significant about their learning that day. Several aspects of the class stood out in these reflections in addition to specific aspects of design being mentioned as important insights from the class. Educators who wish to implement these learning activities would be encouraged to incorporate them. Specifically, through the class activities the students demonstrated that 1) the opportunity to learn from their peers was highly valued, 2) they felt like they were part of a community of their fellow students, with the distribution of students from several cohorts in the departments seen as a positive aspect of the experience, 3) they seized on the opportunity to push themselves to be creative and artistic in their work (and in several cases attributed motivation to do so based on their inspiration from fellow students), and 4) they expressed that learning from fellow students helped them to understand the concept of perspective in a much broader frame.

While we can argue, from both theoretical perspectives and our analyses, about the significance of these tasks for students, the students themselves were also aware of the significance as indicated by end of class comments from three of the students:

> *"…[T]wo assignments were very large, and gave me a stronger sense of process and methodology within my definition of design. The two projects [DB1 and DB2] had us analyzing and representing someone else's design process, and our own design process, respectively. These assignments were the standout for me. Not only did I get to figure out a great way to represent the two design processes for the group, but I got to see and talk to the other students about their representations in depth. I remember [another student] made two physical pieces to discuss, and [another student] made a colorful diagram to show the different methodologies over time. I thought the most interesting thing about this process was using a design process to create a representation we could use to talk about a design process. From these two experiments in design, I came away with a very good idea how methodology broadens the knowledge used to create effective designs."*
>
> *–Student One*

> *"One of the most valuable exercises I feel that we did in the class was the first Central St. Martins project [DB1]. While the actual information was interesting, it was the work we did designing the representation for the tasking the participants did that really helped me to understand the benefits of diverse tasking during a design process. It exposed me initially to the concept of grouping different aspects of design, and understanding how they are beneficial. For the rest of the quarter, I have used that understanding and*

*knowledge to shape my experience in the course work. I hadn't realized that planning out how you are going to design can actually assist you in creating better and quicker solutions. Often, I have just chugged away at a design task, jumping to whatever I think needs to happen next, and don't have much a plan going forward. Understanding this, I am better able to comprehend prototyping and coming up with alternative solutions, instead of generally just one which is what I am prone to do."*

*–Student Two*

*"After going through all the different exercises, and culminating with having to come up with a memory aid to help cement what we learned into our memories and take with us out into the world, I'm excited to see if [it] sticks in the long term. In the end, my definition of design morphed from an abstract definition of my interpretation of what I thought design was, to a much more structured and methodical process."*

*–Student Three*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## Appendix A

# CENTER FOR ENGINEERING LEARNING & TEACHING

University of Washington

Design Research & Application

## STUDYING STUDENT AND EXPERT ENGINEERING DESIGN PROCESSES

### ENGINEERING DESIGN PROCESS

The CELT team is engaged in ongoing studies of the engineering design process to better understand the role of engineering education and years of experience in shaping individuals' engineering design processes. As a framework for our studies, we have synthesized a prescriptive model of the design process from several engineering texts.

| DESIGN STAGES | DESIGN ACTIVITIES |
|---|---|
| Problem Scoping | (Identification of a Need)<br>Problem Definition (PD)<br>Information Gathering (GATH) |
| Developing Alternative Solutions | Generation of Ideas (GEN)<br>Modeling (MOD)<br>Feasibility Analysis (FEAS)<br>Evaluation (EVAL) |
| Project Realization | Decision (DEC)<br>Communication (COM)<br>(Implementation) |

### RESEARCH STUDY

As an extension of our previous research on engineering student design processes, we compared the design behavior of student and expert engineers. Experts (n=19) from a variety of engineering disciplines and industries each designed a playground in a lab setting, and gave verbal reports of their thoughts during the design task. Measures of their design processes and solution quality were compared to existing data from first-year (n=26) and senior (n=24) engineering students on the same design task. Design process timelines (right) were also generated for each participant to make visually explicit when and for how long the participant was engaged in the design activities during the overall design session.

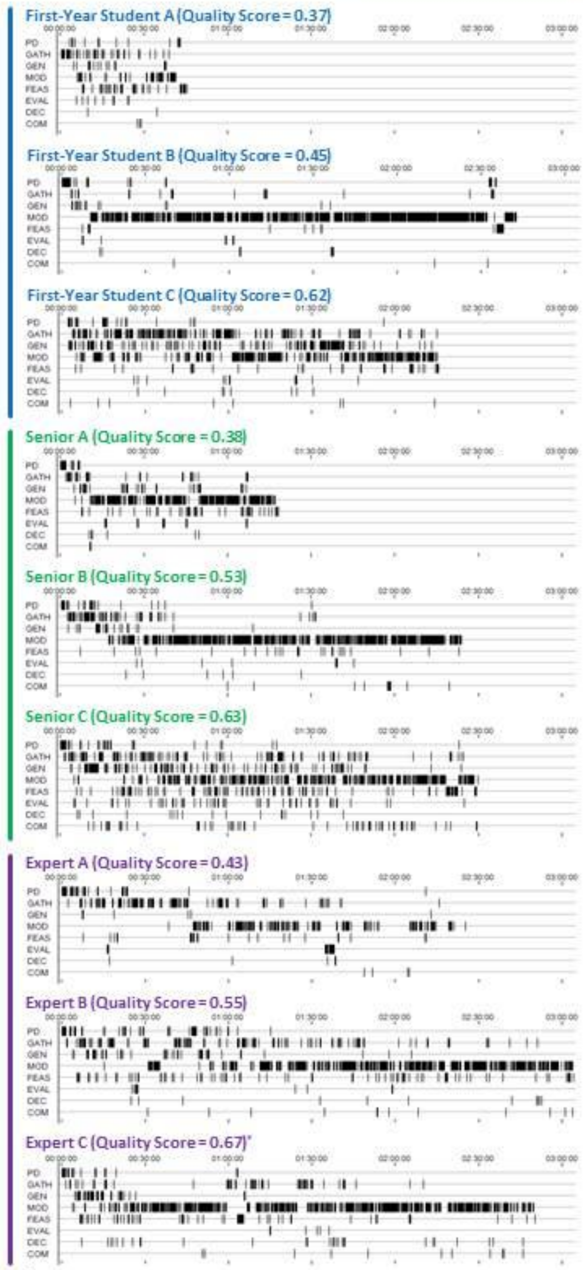
### SUMMARY OF STUDY FINDINGS

Statistical tests show that, compared to the engineering students, the engineering experts...

- Scoped the problem more effectively,
- Gathered more information,
- Covered more categories of information, and
- Spent more time in all design stages.

In addition...

- Experts and seniors had similar quality solutions.
- Experts considered more objects during design.
- Experts tended to exhibit a "cascade" pattern of transitions through the design activities.




*Note that Expert C's timeline exhibits two cascade patterns.


C. J. Atman, R. S. Adams, M. E. Cardella, J. Turns, S. Mosborg, and J. Saleem. (2007). Engineering Design Processes: A Comparison of Students and Expert Practitioners, *Journal of Engineering Education*, 96(4), 359–380 . Recipient of the 2008 *William Elgin Wickenden Award from the American Society of Engineering Education.*

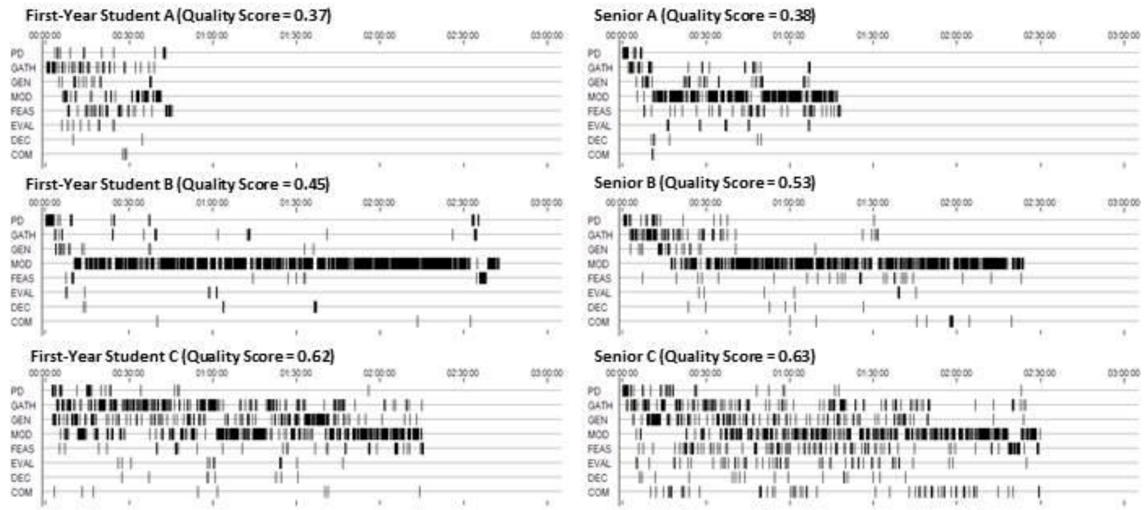
# Bringing Research Findings To Engineering Classrooms

### Current Projects

The CELT team has collaborated with engineering instructors in capstone design and other project-based courses to improve their students' awareness of the components, complexities, and benefits of well-planned and well-executed engineering design processes. We have developed interactive seminars where students analyzed the design process timelines, discussed insights with their peers, and reflected on their own design processes. Students in one class exercise, for example, were asked to examine a set of freshmen and senior design activity timelines (below) and to tell us what they found.

### Class Exercise

In the design process timelines shown below, what similarities and differences do you see between the first-year and senior engineering students? Do these similarities also involve the quality scores? How so?




### Selected Student Insights

*"Problem definition is key to the overall project. Remind yourself of what you are doing and what is really being asked. Pick your head up from the paper (Modeling) and analyze the problem."*

*"Realization of how the design process moves from one portion to the other was the best aspect of this talk. I didn't realize how important the reiteration of certain aspects of the process [are]."*

Another student compared the "Graduating Senior" timeline (below) to those of other students and concluded that an effective design process might be characterized as having a particular shape that he labeled an *"Ideal Project Envelope."*

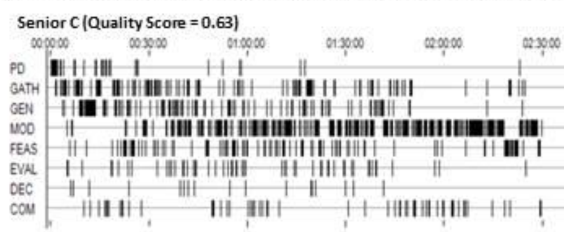



**Figure – Design Process Timeline**

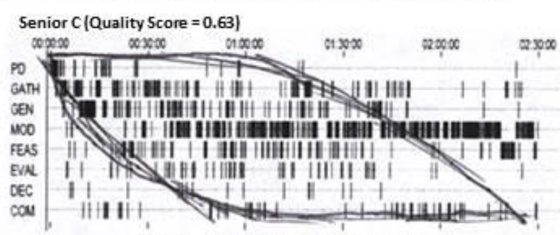



**Figure – "Ideal Project Envelope"**

The ideal project envelope is something our researchers previously identified and termed a "cascade pattern," seen most often in experts' timelines (reverse). This cascade pattern contains a full range of design activities and suggests a way of moving through those activities over time. Importantly, for experts and the more proficient senior students, significant time is spent in early problem-scoping activities, such as information gathering and considering the larger context of the problem.

J. Borgford-Parnell, K. Deibel, and C.J. Atman. (2010). From Engineering Design Research to Engineering Pedagogy: Bringing Research Results Directly to the Students. *International Journal of Engineering Education, 26*(4), 234–245.

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