Piecemeal Versus Integrated Design: Framing meets Design Thinking

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Abstract: Systems thinking is an important component of engineering design thinking but one that is often difficult for beginning designers. In this paper, we present an empirically grounded case that sometimes the novice-like design behaviors emerge, not due to a lack of skills/knowledge on part of the student designers, but by the nature of the way the activity is structured and the implicit and explicit messages communicated to the students on the nature of the design task. Our analysis draws on video-records of brainstorming and design review and briefing meetings between students, instructors, and stakeholders in the context of a service-learning course. The project involved designing a treehouse for campers with disabilities. Our analysis flags a central tension participants faced: whether students were expected to create a piecemeal set of disparate design elements, or an integrated overall design concept for the treehouse. We find that an ambiguous framing by stakeholders coupled with a reification of the design as piecemeal through individual moments of activity and conversation, largely produced a framing and a resulting product of piecemeal design.

Keywords: framing, integration, systems thinking

1. Introduction

The importance of design to engineering practice and hence engineering education is widely acknowledged. In engineering programs, capstone design courses are nearly universal and freshman design experiences are becoming increasingly popular (Dally & Zhang, 1993; Dym, 1994; Froyd & Ohland, 2005; Mikic & Grasso, 2002; Pimmel, 2001; Sheppard & Jennison, 1997; Todd, Magleby, Sorensen, Swan, & Anthony, 1995; Tooley
Supporting these efforts, engineering educators have started to explicate the nature of “design thinking” (Adams & Atman, 1999; Brown, 2008; Dörner, 1999; Dym, Agogino, Eris, Frey, & Leifer, 2006; Dym, Little, & Orwin, 2004; Pahl, Beitz, & Wallace, 1996; Rowe, 1991).

Investigations into design thinking have looked at both expert and novice designers. Research on expert/advanced engineering designers argues for “the complex processes of inquiry and learning that designers perform in a systems context, making decisions as they proceed, often working collaboratively on teams in a social process, and 'speaking' several languages with each other (and to themselves)” (Dym et al., 2006). Expert engineers move through the design process systematically but not rigidly, scoping the problem, exploring multiple solutions, integrating knowledge from various sources, evaluating their assumptions, progress and goals, deciding on optimizations, and iterating through these steps as needed (Adams & Atman, 1999; Atman, Chimka, Bursic, & Nachtmann, 1999; Dym et al., 2006; Hybs & Gero, 1992; Pahl et al., 1996). Novices, on the other hand, tend to spend less time planning, do not explore multiple solutions, and are less adept at evaluating their decisions and monitoring their progress and goals (Adams & Atman, 1999; Atman et al., 1999; Cardella, Atman, Turans, & Adams, 2008; Condoor, Shankar, Brock, Burger, & Jansson, 1992; Smith & Tjandra, 1998). There are also expert-novice differences in what aspects of design thinking they rate as important (e.g., activities vs. knowledge), reflecting differences in their design epistemologies (Adams & Atman, 1999; Adams & Fralick, 2010).

In this paper, we want to add to the design thinking literature in two ways. One aspect of design thinking that has been under-emphasized in the expert-novice literature is the notion of piecemeal versus integrated design. Integration becomes especially relevant for projects that include multiple components. The failure to integrate components that might be individually well designed—but that haven’t been designed to fit well together—is often a weak point for design, even in professional settings.

Our second point is that while studies point to expert-novice differences in design activities and conceptions of design, they provide limited insight into why novices do (or don’t) engage in particular aspects of design thinking. Empirically-grounded causal accounts of how students engage in particular behaviors when designing can help to refine theoretical accounts of design thinking and also suggest instructional pathways toward expertise. Towards our objective of creating more causal accounts of why students engage in particular design behaviors we draw on the socio-linguistic notion of framing (Goffman, 1974; Tannen, 1993). Put simply, ‘framing’ is the participants’ answer to the question “what is the nature of the activity” that is taking place (Goffman, 1974). Participants’ notions of the nature of their activity can affect which sets of intellectual and material resources they draw upon and how they direct their attention to different aspects of the activity. Within physics education research, the notion of framing has helped researchers develop insights into how students approach problem-solving (Bing & Redish, 2009; Elby & Hammer, 2010; Gupta & Elby, 2011; Hammer, Elby, Scherr, & Redish, 2005; Scherr & Hammer, 2009). For example, framing a collaborative problem-solving activity as ‘having a discussion’ is associated with students’ drawing on their everyday knowledge and trying to integrate it with the material they are learning, as
evidenced (among other things) by their construction of multi-step causal explanations. On the other hand, framing the same activity as ‘filling out a worksheet’ is associated with students working individually and focusing on answers rather than explanations (Scherr & Hammer, 2009). With respect to design, explorations into framing, then, should address the basic question of ‘what is the nature of the design activity being pursued?’ We make the case that students’ designing behavior is influenced by their expectations about the nature of the design task (or of “design” or “engineering” more generally) and their framing of the design activity. For instance, if students enter a design task with the expectation that science and engineering consist mostly of using well-defined rules and equations, they are liable to frame their design task as finding the one “correct” solution to the design problem, perhaps leading them to focus too much on “finding the right equation” and too little on thinking qualitatively about the real-world constraints and affordances for the system to be designed.

This sense of design expectations connects to the notion of design lenses (Adams, Daly, Mann, & Dall’Alba, 2011; Crismond & Adams, 2012). Adams and her colleagues argue that a designer’s approach to a given part of a design task can be characterized in terms of a design lens — a way of framing the nature and goals of the task coupled with a particular set of knowledge and skills that the designer brings to bear. For example, if a designer views a design task through a lens of personal synthesis, he or she will likely consider personal experiences and previous knowledge, seek out new information, and attempt to connect those knowledge pieces together to inform possible design outcomes. By contrast, as previous work suggests (Downey et al., 2006), conceptualizing a design task as finding the one right answer — a “narrow” lens for viewing design — could lead to a focus on finding the right equations, as mentioned above. If a designer views her task through a lens of intentional progression (Adams et al., 2011), he or she is likely to focus on previous related work that the new task could build upon and the broader impacts of the work beyond the immediate project. Research on engineering design has also drawn on the notion of framing, drawing on the work of Schon (1984). For example, Valkenberg and Dorst (1998), Dong, Kleinsmann, and Deken (2013), and Stumpf and McDonnell (2002) analyze design team discourse to understand how teams develop shared problem frames—for instance, whether the design task is to throw a ball vs. roll a ball at a target—within which design moves can take place. Establishing shared frames across all team members correlates with better progress on design tasks. Our definition of framing includes a shared understanding of the design task but also includes participants’ sense of the nature of a design activity (and of “design”) more broadly (e.g., as an opportunity for personal synthesis, in Adams et al’s language), as well as participants’ sense “what’s going on here” in a participant social or classroom interaction. In this paper, we use the notion of ‘framing’ to focus on whether and how students are engaging in piecemeal or integrated design of an accessible treehouse for children with disabilities.

Methodologically, most previous studies on the design thinking of novices and students have relied on surveys (Adams & Fralick, 2010), field notes (Cardella, Atman, & Adams, 2006; Cardella, 2010), written inscriptions (Hill, Dong, & Agogino, 2002; Ullman, Wood, & Craig, 1990; Yang, 2003), or think-aloud protocols for individual students.
performing a design task (Adams & Atman, 1999; Atman, Cardella, Turns, & Adams, 2005; Atman et al., 1999; Smith & Tjandra, 1998). For our investigation, we will rely on videotapes of teams engaged in a design task, and of design team meetings with various stakeholders.

2. Data and Methods

2.1 Data Selection

The data for this manuscript are drawn from the corpus made available for the Design Thinking Research Symposium, 2014 (Adams & Siddiqui, 2013). The data corpus consisted of video records of design teams engaged in design activities and design reviews as part of six semester-long courses:

1. a semester long choreography project for a public performance
2. a semester long Entrepreneurial Design “capstone” course for undergraduate students in the Entrepreneurship Certificate program
3. a semester long Industrial Design course for undergraduate students in their third (“junior”) year of a four year program
4. a semester long Industrial Design course for graduate students
5. a semester long Mechanical Engineering senior design or “capstone” design course
6. a service-learning design course in which teams of students from across campus work together on long-term projects that benefit the community

The first level of selection was made by DTRS organizers, in creating a shared data set that all participants could make further selections from. As outlined in the documentation provided with the data sets, “The guiding principles for selecting the samples from the larger dataset focused on providing the highest quality data for:

- Ease of analysis (e.g., quality of digital video and audio)
- Ease of sharing (e.g., compressing digital video into files that could be effectively downloaded from the system)
- Relevance for analyzing design review situations (e.g., multiple in-depth comparative examples that span different design review structures and modalities, phases of design, level or type of interaction, etc.)
- Depth of analysis (e.g., multiple examples are provided to be able to substantiate patterns)
- Longitudinal analyses (e.g., following students or teams over time, which in some cases involved broadening the number of examples so there were always 2-3 examples per design review phase)
- Comparative analyses (e.g., one-on-one and group situations, disciplinary and interdisciplinary situations, different design review phases, etc.)”

We selected the Service Learning set for our analysis. This set was unique in terms of including an extended brainstorming session where students shared ideas among themselves. We thought that having access to a session where students’ ideas are not
being reviewed or evaluated by instructors, experts, or stakeholders might provide additional insights into students’ design thinking.

2.2 Description of Selected Data

As described in the documentation provided with the data set, “The context is a service-learning design course in which teams of students from across campus work together on long-term projects that benefit the community … This particular experience was a special 3-week, 3-credit hour offering which was a partnership with The Camp and [Location]. The Camp is a summer camp for children with disabilities held at [Location], a 2,500 acre universally accessible outdoor recreational facility. Although the camp is very accessible, there are still barriers for the children to be able to participate fully in all of the activities. This project focused on designing ways to overcome some of these barriers. In particular, it focused on the design of a universally accessible treehouse.” There were 11 undergraduate students and 1 graduate student on the targeted design team. The supervisory team consisted of the instructor, a student advisor, and the camp organizers. The video-records that make up this data set are shown in Table 1 below.

Table 1. Description of Video Records

<table>
<thead>
<tr>
<th>Name</th>
<th>When</th>
<th>Participants</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partner Debrief #1</td>
<td>Week 2 - Tuesday; on camp site</td>
<td>Camp Organizers, Instructors, Students</td>
<td>~40 minute meeting among participants to discuss camp objectives and the specific design objectives</td>
</tr>
<tr>
<td>Brainstorm Review</td>
<td>Week 2 - Wednesday; on camp site</td>
<td>Students, student supervisor</td>
<td>~60 minute session where students present design ideas to each other</td>
</tr>
<tr>
<td>Partner Debrief #2</td>
<td>Week 2 - Wednesday; on site</td>
<td>Students, stakeholder</td>
<td>~30 minute meeting between a few students and a stakeholder (camp organizer) to discuss and clarify issues</td>
</tr>
<tr>
<td>Advisor Debrief #1</td>
<td>Week 2 - Thursday; on camp site</td>
<td>Instructor and student advisor</td>
<td>Participants met briefly (~11 minutes) to discuss student progress and instructional actions</td>
</tr>
<tr>
<td>Advisor Debrief #2</td>
<td>Week 2 - Thursday; on camp site</td>
<td>Instructor, student advisor, students</td>
<td>Short meeting (~11 min) between participants to discuss current status and next steps</td>
</tr>
<tr>
<td>Partner Review</td>
<td>Week 2 - Friday; on camp site</td>
<td>Camp Directors, Students, Instructor, student advisor</td>
<td>~19 min meeting where students present design ideas to the camp organizers</td>
</tr>
<tr>
<td>Advisor</td>
<td>Week 3 -</td>
<td>Instructor, students</td>
<td>Students reflect on their experience</td>
</tr>
</tbody>
</table>
Our analysis covers this entire data set, except the Advisor Debrief #3. This clip consists mostly of affective and interpersonal reflections rather than reflections on the nature and quality of their design process or what their final deliverables should be. As such it did not add to our understanding of how the students (or instructor) were framing the design task. So, this video is not included in the analysis.

### 2.3 Analytical Workflow and Methodology

We started by watching the videos and transcript from the Service Learning set individually, marking places that stood out as interesting or important to us in some way. In these initial phases, another researcher in our group, Gina Quan, was deeply involved; but she later withdrew due to competing demands on her time. In group video sessions, we watched these marked portions together, articulating to one another what meaning and interest we were individually deriving (Derry et al., 2010). These articulations fell into two grain sizes: at a finer grain size of attending to specific utterances and interactions between participants in a setting, and at a coarser grain size of understanding how participants might be broadly construing the nature of the immediate activity in which they were engaged. In group discussions, we also tried to integrate these two grain sizes, making sure the finer-grained interactions were not inconsistent with our explanations of participants’ framing of their activity. When an explanation seemed plausible to multiple research group members, or if there were multiple plausible explanations, we tried to use a particular explanation to predict how participants would interact in the segments we had not yet watched together. Through such iteration, we could rule in some explanations as more plausible than others. We did not assume that participants’ framing of their design activity for the camp as a whole would be the same across settings; but if we posited shifts in the framing, it was important for us to be able to explain that shift in terms of local interactions and/or particular features that might have changed between settings.

Through such group video analysis, the tension between piecemeal design and integrated cohesive design emerged as one lens through which we could interpret large swaths of the data. This is not to say that other kinds of analysis cannot be brought to bear on this data. We claim only that this particular tension is one productive analytical lens for this data.

Subsequent analysis focused on how this tension manifested itself and played out in explicit negotiations among stakeholders and (more implicitly) in how students pursued design. When analyzing the meetings of students with other stakeholders (camp organizers and instructors) we focused on messages being communicated to the students and negotiations between students and camp organizers and instructors. For this, we drew on the explicit content of the speech (of various participants) as well as on implicit
messages embedded within the speech (through emphasis, omission, and ambiguity). To understand how students pursue the design, we primarily drew on the “Brainstorming” episode. For that we analyzed what students attend to in presenting their ideas and orienting to other students’ ideas, and the flow of activities moderated by the student facilitator to infer how participants are framing the nature of their in-the-moment activity and how that framing relates to the issue of piecemeal versus integrated design.

Framing, viewed as a participant’s response to “What is it that’s going on here?”, need not have a single answer: multiple frames can be seen as overlapping or nested. Thus, in our analysis, participants’ framing of a particular local interaction as “show and tell,” “an evaluation meeting,” “brainstorming ideas,” or other, is nested inside a coarser-grained framing of their broader design activity as piecemeal or integrated design. In part, what our analysis demonstrates is how framings at finer-grain sizes might interact with and stabilize particular broader framings of the design task.

3. Analysis and Results

We present our analysis of the episodes chronologically below.

**Partner Debrief 1- Framing the Overall Design Process**

In the first partner debrief, we attend to the ways in which the camp organizers and students make visible what they think is the nature of the activity. In this interaction, we notice that the camp organizers are positioned as experts while the students are positioned as novices about most aspects of the camp, including camper experience, safety, and feasibility. Overall, as illustrated below, the activity is framed largely as “giving an assignment,” wherein the boss-experts (organizers) tell the employees (students) what to do. Within this framing, students are allowed to ask specific clarifying questions but not to negotiate the assignment. For example, when Sebastian (student) asks Michael (organizer) to clarify the students’ role in the process, Michael positions himself as an expert on feasibility, safety, and environmental factors, while positioning students as novices who might have creative new ideas because they “don’t do this designing day in and day out” (Michael). This is important, because the asymmetry in the positioning of students versus the camp organizers has implications for who gets to define the nature of the design activity as we see below.

Although camp organizers speak about the treehouse in general, they do not address exactly what they want the students to do for them as part of the treehouse design project. Mackenzie brings up the central question of framing the task in minute 21:00:

I have a question for you guys. Um, so in terms of like – well, like what exactly would you like the most useful thing we can give to you to like to use? Like do you, do you want an actual like kind of undeveloped design that's kind of like rough? Do you want a list of ideas or things that we think would be great to incorporate? I mean what is gonna be most useful to you in terms of, of making this real?

Note that contrary to some prior parts of the video where students are looking down at their notes, looking off into space, etc., all students and organizers visible in video shift
their attention to Mackenzie during her question, indicating that this is a relevant question for all stakeholders. Todd (organizer) nods in agreement during the question. Later in Advisor Debrief 2, Cate mentions this as a “really great question.” As Mackenzie finishes her question, most participants turn their attention back to the center of the group or others in the group; some are smiling and beginning to laugh:

*Long pause from students and organizers, some nervous laughter.*

It should be noted that, despite being positioned as a novice, Mackenzie’s question shows design expertise in seeking to clarify the nature of the task before focusing on details of the design. In essence, Mackenzie is asking a fundamental design question which all of the camp organizers have ignored for the past 20 minutes, and in so doing she is also partially shifting the framing from that of a boss giving instructions to a design team seeking clarity on the nature of the deliverables. The students’ attention suggests that students are aware of the question’s importance. One of the camp organizers, Dominic, tries to answer Mackenzie’s question, but his response lacks the clarity that Mackenzie was seeking:

*Dominic:* I could say yes to all the above.

*Continued/increased laughter*

We take the laughter after Dominic’s response to indicate recognition, within the group, that the response does not quite address Mackenzie’s question. The nervousness apparent in the laughter before and after Dominic’s response could be an indication that there might be something uncomfortable about the lack of a clear answer for what students should be doing. Todd, the Camp Director, follows up on Dominic’s response:

*Todd:* – yeah. You know, obviously, there's, there's some sense of, you know, not doing the finished design as Michael was talking about, obviously, there's weight considerations structural stuff that needs to be gone through. Um, by all means, rough designs or designs plural that incorporate some of the ideas I was hoping you guys could add, and in terms of the kids have had, some of the [ideas] the kids have, would be awesome.

Todd acknowledges that the finished design with weight considerations and structural stuff will not be a major element of the students’ design. He contrasts that with what students can do-- “rough designs or designs plural that incorporate some of the ideas,” mirroring Mackenzie’s use of the word “rough,” though indicating plural “designs” where she was referring to a single rough design as an optional deliverable. Through “designs plural” Todd seems to indicate that he at least values multiple ideas. It is not clear, however, whether he wants designs that fully integrate the different components of the treehouse or piecemeal design elements that the camp organizers can integrate into their own ideas.

Michael, the landscape architect working with the camp organizers, follows up on Todd’s response, characterizing his expectations for the student design task slightly differently from Todd:
Michael: This is a big great space, so design elements whether particularly interesting or innovative that you might be able to dream up to we may not think of or the designers may not think of, um specifically with assisting these kids that, um, might not be common sense to us with creating lot of design over and over, but this is something unique that you can—wrap your minds around.

Michael’s response seems to reassert his expertise and his control of the design in general, in that students will be offering interesting and innovative “design elements” that “might not be common sense” to the veteran designers who “create[e] lot of design over and over.” The mixed responses of the stakeholders become pivotal as students negotiate their further work on the project, reminding themselves what it is they have interpreted themselves as needing to do.

In response, Cate (the students’ instructor) makes a bid for lessening the cohesive design role of students:

Michael: But as far as getting into the, you know, the detail design or structural or spatial relationships… [unintelligible, seems to say something about important structural work his team can handle. Cate nods her head vertically at the beginning of the statement, and shakes her head at the words “detail design”—seeming to agree with the sentiment of the statement and to write off doing structural elements as out of the question.]

Cate: And none of us have that expertise. We have one PE over, the T/A…that’s it. [Unclear. Perhaps “Most of us are not even…” engineering majors / backgrounds. She is looking around, scanning the group and describing their abilities at this point.]

Todd: Yeah but obviously, you know, it’s not a totally unrealistic conceptual sketch either because you guys, you know the existing trees and the platforms [up there now, so], you know, some really…[unintelligible].

Cate: Oh, we just recognize our limitations. [Gestures in a circular horizontal motion suggesting constraining within a sphere of capability.]

Todd: Yeah… [nodding, looking down].

Here Todd’s suggestion for “not a totally unrealistic conceptual sketch” (in the singular) seems to suggest more work towards a tentative cohesive design for the treehouse. Taking into account both of Todd’s statements in this section, we can gather that Todd’s clarification was probably not asking Cate’s team to do the “detailed structural calculations” which one minute earlier he had said were not expected. It seems more likely that he is clarifying that this work can still result in a realistic “conceptual sketch” of a treehouse without requiring detailed calculations, possibly more oriented towards integration than the design elements framing. Cate had a lot more markers of agreement with Michael’s statement than with Todd’s. Thus Cate seems to subsume Todd’s proposal of a possibly cohesive deliverable into Michael’s request for design elements, viewing Todd’s input as a negligible exception to an already decided (Michael’s) project direction. In doing so she seems to willingly abdicate responsibility for this sphere of the project, based on the team’s background and limitations.
Brainstorming Activity

The brainstorming activity is the chronologically next event in the dataset, and is the first and only example of student design work. The activity is organized by Joel, a graduate student leader, and all student team members appear to participate. Cate (instructor) and camp organizers are not present. Joel was present during the partner debrief, but did not speak. After the Partner Debrief 1 and prior to the Brainstorming Activity, it appears students have interacted with campers to become more familiar with the way the camp works, as they reference several such experiences during the Brainstorming Activity.

As the video starts, we see Joel giving instructions for a transition in the brainstorming activity. Students had been sitting at desks after placing post-it note design ideas in categories around the room, and now they will be moving to each section of the room to discuss their ideas. Several elements of the brainstorming session warrant attention for the ways in which they guide and constrain the design process along a trajectory of compartmentalized (piecemeal) design. The design has been broken up into categories, either elements (ramp) or functions (safety). Individual students have drawn ideas within each category, and the importance of correct categorization is highlighted repeatedly. Further, the small size of the post-its constrains student output to relatively simple discrete ideas, and the physical and temporal separation of the design categories in the brainstorming session constrains looking across categories. Joel frames the activity (later termed “ideation”) as largely a show-and-tell of ideas:

But now just introduce our ideas first, and see what everyone thinks. So probably we start from the ramp and accessibility. So who draw the first one, and you just go ahead and explain the idea.

To be clear, even in a design project where a cohesive final product is desired, an initial brainstorming activity or ideation phase may often be conceptualized this way. Thus it is not clear from this setup alone whether participants conceptualize their broader activity as cohesive vs. piecemeal design. What we can observe is that the initial “show and tell” framing stressed the importance of design elements / piecemeal design to some extent, and that certain factors lead students further down a path of compartmentalized design, which we could imagine may or may not continue after this point.

In spite of most of the structure of the activity being towards a compartmentalized overall design, there are several examples of students collaborating and connecting across design ideas, elements, or functions. These are short-lived, however, as the structure of the activity inevitably moves them on to the next design idea or functional element and disrupts the flow of collaborative/cohesive design thinking. For example, the idea of interspersed flat sections of the ramp was suggested and then given several new functions by different participants: initially as a resting area, then as an element of educational information, then doubling as a cheering session. These moments of cohesion tended not to be pre-drawn post-it note ideas from individuals, but rather were collaboratively constructed by talking across ideas. Other examples of cohesive and collaborative design included bids to incorporate dual roles of ramp railings as trees (for safety, tactile/sensory, nature exposure, and environmental responsibility / recycling reasons),
and considering transparent elements to several parts of the ramp and treehouse (for safety, fun, and exposure to nature reasons). But again, these types of discussions did not extend beyond the discrete time and space allotted by the structure of the activity.

The eventual purpose of this brainstorming can be most clearly seen in the way the session concludes. Joel praises the students for their drawings and ideas, mentions that they should incorporate the lake as a physical site element, and continues with:

*Joel:* And – that's the problem that I saw from, um, ah, *what I come out from the ideation.* And I think the second step, *because we already have a lot ideas, and it's really good ideas.* So if we keep on going the same, same process it may just make the whole process hard to level down.

*Mackenzie:* Mm-hmm.

*Joel:* So I will say choose one – I have suggestion, like probably, you can choose one of the cool idea, and really build a quick mockups off that. So using the paper that we have, like just build a quick mockup of that to show you idea in a more clear way, because this drawing is not enough. So that's one suggestion, you can – if you don't like really mockup, you can just draw it in a clear way. Or if you have more idea you wanna put inside, just put on top and – so if there are three solutions for the next steps, so I'm not sure you guys have any problems when-- you think it's ideation or any suggestions for this. I think I any suggestion for this? I, I just give my advice.

*Naomi:* Okay, What – *can you explain that check system?*

*Joel:* Oh, ah, we also have the check system for choosing the idea-, id-, id, id- idea, sorry. *We note we are missing some initial framing of the Brainstorming activity. This is the first time checks are mentioned in the transcript*

Mackenzie: And, ah, so, um, so it's first set up a goal. So, ah, for our presentation because *I heard from Ellie* that, ah, *probably it's better that we explain* each idea – not – each idea – *each components* for the – as the presentation like. So it, *it's not really showing them a full tree house,* but just tell them, for example, nature and what kind of ideas that we have. *Like that presentation way.* Ah, so *I'm not sure you guys would like to do this way or not,* but if we do this way, we can set a goal. So, for example, *each component I want to show five concepts.*

*The brainstorming session further concludes with some discussion of the correct categorization of ideas like the moss wall (structure, sensory, or nature) and the telescope.*

Thus the brainstorming session, which was structured to generate several compartmentalized design ideas, is now leading to drawing the best design elements carefully on larger sheets of paper and (as becomes clear) bringing them to discuss with campers and camp organizers. Joel signals that what is most useful at this point (if not implicitly for the project as a whole) is to highlight and make more clear the best individual design ideas. This strengthens the broader framing of the project as compartmentalized design, in which “show and tell” was embedded to help identify the
best compartmentalized design elements to develop further. Thus, the participants’ activity moves further along a compartmentalized design trajectory in a way that was not inevitable. We can imagine, for instance, a different way to wrap up the brainstorming session, if cohesive design were foregrounded: encouraging participants to seek out design element interactions, synergies, and conflicts with the goal of shifting focus to an overall treehouse design concept and which elements fit best into it. We note that instead the selected process for winnowing down design ideas, voting on which individual ideas are the best without considering how they do or do not fit together, reinforces the compartmentalized design framing of the broader activity.

**Partner Debrief 2**

Although we do not have video from more of the students’ design sessions, we have some indication from the videos that follow that the design team continued to conceptualize the design as piecemeal rather than integrated. In Partner Debrief 2 we see selected students interacting with Todd, a camp organizer. Although students have come out of their prior activities concerned about how to design for safety in light of other requirements (e.g. open windows to increase exposure to nature present opportunities for falling), Todd tends to offload the safety concerns and specific legislative constraints to Michael. To some extent, this represents students making a bid to engage in a more integrated design which balances safety concerns with other design requirements, and camp organizers rejecting the bid, shifting student responsibility away from integration. Although this may not have been Todd’s intention, his response may further reinforce a compartmentalized design framing.

**Advisor Debrief 1**

Advisor Debrief 1 sees Cate and Ellie having a private conversation wherein they discuss next steps and deliverables. Most of the talk here occurs around presentation of design elements to campers, and discovery of new design elements and specifications from campers, thus largely continuing the framing of the project as producing compartmentalized design elements. To the extent that Cate and Ellie are the design team’s leaders, their impressions of the project direction are significant markers that compartmentalized design is the primary nature of the project activity at this point.

**Advisor Debrief 2**

In Advisor Debrief 2, Cate is checking in with students on their progress towards the final partner meetings. Cate recalls Mackenzie’s initial question during Partner Debrief 1:

* Cate: “Um, Mackenzie, you asked a really great question, and um, like Michael everybody, um, they what would be useful for them. And so they really said a rough design, right, and then design elements. So how are you gonna capture those design elements?”

Here we see Cate summarizing the camp organizers’ responses in a cleaner way than they were originally presented, as essentially two prongs: rough design (Todd’s words) and
design elements (Michael’s words). And yet, she follows up on how exactly the design elements are going to get presented (sketches, descriptions), without addressing whether these two prongs are also the design goals, what “rough design” means, or whether students have met that part of the design brief. This seems to align with Cate’s earlier agreement with Michael during Partner Debrief #1, and resistance to or misunderstanding of Todd’s characterization of the expectations of the team.

**Partner Review**

Finally, in the Partner Review, we see an initial student presentation given to two previously unknown camp organizers (one of whom, Male 1, we believe is named Shay). The presentation is largely structured around the categories and design elements from the brainstorming session, with a description of specifications for the treehouse and how they were arrived at (whether there is conflict between stakeholders), and the large white paper design idea mockups as prominent solutions in each category. The presentation is met with a lot of enthusiasm by the camp organizers, yet Shay highlights an element of the design output he is missing from them so far:

*Male 1*: Great. Um, will your model be – will it – you know, I want to give this to Abby Inc. and one of the things they need to know is how long and how wide, the interaction of trees. Will it include all those specs in it?

[Students and Cate explain that they have not done this detailed work, because they didn’t want to “tread on shoes,” and “didn’t really have that expertise.”]

*Male 1*: Yeah, just a rough estimate would actually help for building materials.

[Cate and the students then agree that they can carry out the request.]

We highlight this video selection as tentative evidence that there was some breakdown in the communication of design goals. It appears that at least one of the camp organizers wanted some level of cohesive design, while the design team interpreted their role as only providing piecemeal ideas. Without further data from other interactions, we cannot be sure who has contributed what to the miscommunication: it seems that disagreements of the design purpose existed between camp organizers, between the organizers and the instructor and students, perhaps even between the students/instructor team members themselves. There is tentative evidence of mis-interpreted design goals. It also appears to be the case that some choices of the design team (e.g. brainstorm activity structure, idea to redraw isolated post-it note ideas onto cleaner versions for presentation) led students down a path of compartmentalized design without a full reckoning with the big picture goals of the project at each moment.

**Final Review**

In the Final Review we see some evidence that student designers have responded to Shay’s (Partner Review) request for at least rough estimates for the specifications as a whole, however most of the presentation is still structured around the original categories and piecemeal solutions / ideas. The students’ approach to designing a cohesive
treehouse layout (for rough costing, spacing, planning purposes) was to have three students try producing overall optimized designs and to vote on the best one. Thus we see student designers are capable of formulating a cohesive design if they consider it their objective, but that the inertia of initial framings and in-the-moment choices of a design project as compartmentalized can shape the project drastically. We note the cohesive designs were produced mainly as an afterthought. They were not conceived of early enough to allow an overall vision for the project to shape their choices and explorations.

4. Discussion

4.1 Integrated versus piecemeal design

Experts in engineering design emphasize the importance of systems thinking, thinking about how the various parts/modules of a project fit together into a coherent, working whole (Dym, Agogino, & Eris, 2005; Frank, 2000, 2002). The distinction between integrated and piecemeal design explored in this study is essentially the distinction between systems thinking and lack thereof. So, when Mackenzie asks “...do you want an actual...design that's kind of like rough? [Or] Do you want a list of ideas or things incorporate?” she is asking whether to engage in (perhaps rough) systems thinking versus thinking about parts but not the whole. To date, few studies of students’ thinking have foregrounded this distinction (examples in non-engineering fields: Assaraf & Orion, 2005, 2009, 2010; call for work in engineering: Dym et al., 2005). One of our goals in this paper is to illustrate how piecemeal (non-systems) design thinking can play out in students’ design work, flagging the distinction between integrated and piecemeal design thinking as a worthwhile and feasible lens through which to analyze students’ design thinking.

4.2 The importance of framing

In the process of trying to explain the genesis of stability of the students’ piecemeal design thinking in this series of episodes, we highlighted the explanatory power of framing, the participants’ sense of “what is it that’s going on here” (Goffman, 1974; Bateson, 1972). Although we highlighted the role of framing in our analysis above, it is worth synthesizing a few points here. A framing often incorporates a goal but is not the same as a goal, for several reasons. First, a framing incorporates more than just a desired outcome. It also incorporates expectations about what roles are available to participants, and what kinds of interactions they can have (Tannen, 1993). Furthermore, and most important, a framing is not something negotiated and set in stone at the beginning of an activity. It is stabilized and/or destabilized by the continuing interactions of the participants with each other and with their material setting. So for instance, as we highlighted above, the “show and tell” framing of the meeting in which students shared their design ideas on post-its was stabilized by factors such as the size and placement (into spatially separated categories) of the post-its and by emerging structure of the conversation in which it is expected that, soon after one idea is introduced, it’s time for another student to present her idea (cutting off extended discussion and integration across ideas). In this kind of framing analysis, the intention behind these factors (e.g., the decision to use post-its) is not important. What’s important is that these factors had the
effect of reinforcing a “show and tell” framing. Similarly, Michael the organizer might not have intended to constrain students’ use of systems thinking. But the various messages embedded in his talk—positioning students as novices and the organizers as experts, delegating concerns over safety and regulations solely to the organizers, encouraging out-of-the-box ideas that experienced designers wouldn’t think of—contributed to students’ evolving sense of the broader activity in which they were engaged.

Another analytically useful feature of framing that contributed to our analysis is nesting. Frames characterizing smaller grain-sized activities can be nested inside frames characterizing broader sequences of activity, analogous to a subroutine nested inside a larger computer program. In our account, a show and tell framing of the Brainstorming Activity is nested inside—and contributes to—the broader framing as their work on the project as piecemeal design. We suspect that this kind of nested framing is pervasive in classroom-based engineering design projects, which include particular classroom activities, homework assignments, and so on. Students’ framing of a classroom activity could be nested within—and contribute to—their broader framing of their design activity on the project as a whole. Or, a student’s framing a classroom activity could conflict with and even disrupt her framing of the broader design task. Our point is the importance of attending to framing at different grain size, examining in what ways smaller grained-sized framings nest within or challenge broader framings.

4.3 Explaining novice versus expert reasoning

As noted in our introduction, literature on engineering design thinking often characterizes the differences between novice and expert thinking but does not seek to explain why novices think the way they do. So for instance, systems thinking is characterized as expert behavior, and piecemeal design (that isn’t intended to contribute eventually to an integrated design) is characterized as more novice-like behavior. When explanations are offered for why students engage in novice behaviors, the explanations typically posit that novices lack key knowledge and/or skills that experts possess. We do not dispute that novices need to develop disciplinary knowledge, skills, and ways of thinking in order to become experts. Nonetheless, our analysis challenges the default explanation for novice-type behavior in terms of underdeveloped knowledge/skills. As discussed above, in the Final Review activity, the participants successfully engaged in integrated design. And in Partner Debrief 1, Mackenzie displayed expert-like awareness of the distinction between integrated (systems) design thinking and piecemeal design—and other students oriented to her question, suggesting that they understood it as important. So, in this case, we cannot explain students’ engagement in piecemeal design by attributing a lack of the necessary skills and knowledge to engage in integrated design. The students could engage in at least rudimentary forms of systems thinking. But the framing of their activities, reinforced at each step, pushed participants away from systems thinking until the Final Review.

Our point is that explanatory factors other than lacking knowledge/skills can help to explain why novices initiate and sustain novice behaviors. And explanatory factors such
as framing have more actionable instructional explanations than do explanations based on missing knowledge/skills. In the case we examined, and we suspect in many other episodes of engineering design, helping students reframe their activity in certain ways could open space for students to leverage knowledge and skills they already have (e.g., knowledge and skills to engage in the beginnings of systems thinking). Similar moves have worked to foster science students’ inquiry. As noted above, when students frame classroom activity as having a conversation or argument over which they possess epistemic agency, students show the ability to engage in the beginnings of scientific argumentation and explanation-building, even without explicit instruction in those practices (Berland & Hammer, 2012; Rosebery, Warren, & Conant, 1992; Hammer & van Zee, 1996). Our analysis in this paper makes it plausible that similar (re)framing moves by instructors, and careful monitoring of how students are framing their activity, could lead to similar successes in helping engineering students engage in the beginnings of expert design practices, including systems thinking.

4.4 Connections to other papers in this volume

Our analysis in this paper examined how participants’ framing of local moments of interaction (and the implicit and explicit messages associated with those framings) interacted with students’ sense of the broader purposes of their design as piecemeal vs. integration. Fleming and Coso (2014) also note the ambiguity of the messages sent to students about whether to engage in piecemeal or integrated design. They specifically address how different strategies for conducting design conversations might have avoided the ambiguous messages from “clients” regarding integration, which our analysis then took as our starting point. We differ from Fleming and Coso in not attributing the miscommunication to the student skills; our analysis locates the communications breakdown in the unfolding interaction. Fleming and Coso’s analysis parallels our own, in that it explicates some other aspects of why the stakeholder discussions do not lead toward integrated design. Finally, Fleming and Coso note how several design elements do not get incorporated into an integrated treehouse product, corroborating our own analysis. A discussion during the DTRS2014 symposium brought up the issue of whether reflective practice, or metacognition, could circumvent such issues. We agree that being metacognitive about what one is doing and why can help disrupt the inertia of an unproductive framing.

A second paper, on the treehouse-project data, by Fila and Hess (2014), examined how empathy contributed to students’ formulation of design elements. This complements our analysis of the students’ brainstorming; we could attribute a “frame of empathy” for the campers that coexists with the frames attributed by our analysis. Particularly interesting for our analysis might be how a frame of empathy for campers affords piecemeal design, since hearing disparate ideas from diverse campers might lead to divergence of new design elements rather than a convergence toward an integrated project. If discussions with campers only took place early in the project, such divergence might have been wholly productive. Yet we know that students discussed design elements with campers at several times. Since these meetings happen off camera, we cannot reach well-warranted conclusions; but it is plausible that the process of divergent empathy at a later stage in the design also contributed to a piecemeal framing. The question of who one empathizes
with (various campers, other stakeholders) and how their opinions get used is central to both Fila and Hess’s analysis and our own analysis, and it is a central question for the human centered design processes.

5. Conclusion

In this paper, we (i) illustrated the distinction between integrated (systems) design thinking and piecemeal design as a worthwhile lens through which to analyze students’ design thinking, (ii) illustrated the power of framing to help explain why students’ engage in piecemeal vs. integrated design, and (iii) argued that novice behaviors can and should be explained (when possible) in terms of constructs such as framing rather than in terms of deficiencies such as underdeveloped skills/knowledge. Specifically, we argued that the implicit and explicit messages communicated to the students, and their continuously-reinforced framings of their subsequent activities, help to explain why they engaged in piecemeal rather than integrated design.

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References


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