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Developing a Bridging Language: Design Decisions in Informal Making Experiences

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1: Introduction

The complex nature of design practice makes it both challenging to teach and to learn [1]. Historically, engineering programs have had difficulty integrating design in their curricula. As a result, both the positioning of design coursework within the curricula and the teaching practices within this coursework vary widely [2], [3]. The shift, over the last few decades, to more practiced-based experiences through project-based learning (PBL) has resulted in a number of positive learning outcomes [1]. However, there is still a call for more practice-based experiences throughout the curriculum [4]. Instead of focusing on packing more into engineering curriculum, we explore the idea of leveraging the many design experiences students are already engaging in by advocating for the development of a ***"bridging language".***

Students are already engaging in a breadth of design experiences throughout their lifetime. Engineering students engage in a number of formal design education experiences - such as cornerstone and capstone classes or design electives - throughout undergraduate engineering programs. Increasingly, students are participating in engineering coursework through their K-12 schooling. Students also pursue professional design experiences - such as internships - during their formal education and following it, when they enter the workforce. We might also say that students engage in a number of informal design education experiences throughout their lifetime. Herbert Simon famously states that "To design is to devise courses of action aimed at changing existing situations into preferred ones". Given this definition, many of students' informal everyday making experiences have the potential to be seen as design.

The maker-movement and growth of makerspaces is a domain where many students participate in ongoing "self-directed project-based learning" (sdPBL) experiences both prior to and during their formal engineering education. Like PBL in formal curriculum, the pursuit of "maker" projects - interest driven fabrication projects - where students carry out a creative process, can be seen as potential design learning experiences. However, these experiences are frequently difficult to relate to the ways of documenting and describing design used in the classroom. Additionally, this environment lacks the scaffolding created in university PBL curriculum for explicitly teaching design concepts and skill. It is unclear to what degree students can learn design through this sdPBL or how best support design learning in this environment. Additionally, there is debate as to whether or to what degree "making" can be considered design at all.

As educators, we do not have much control over the structuring of students sdPBL experiences. However, supporting student's design metacognition [5], [6] or "design awareness" [7] is a promising avenue for student's to begin to make sense of their informal design experiences. In this paper, we call for and explore the idea of a ***"bridging language"*** - A language that can serve as a metacognitive scaffold, bridging across formal engineering design education concepts and the ongoing informal design experiences that students already take part in: A means by which students can capture and make sense of their informal design experiences and relate them back to concepts in formal engineering and their work.

This work is part of a larger research agenda investigating methods for supporting students in capturing and making sense of their informal design experiences. In this paper, we look at a case-study of 6 undergraduate students pursuing self-directed project-based activity in a university makerspace during a 10-week period. We apply a particular framework - Design Space Analysis (DSA) [8] - as a potential means of capturing and making sense of students' informal design experiences through the lens of design decisions and design rationale. We present results in three sections: 1) the scope of students' design decision making and rationale (questions, options, criteria, and rational), surfaced by the application of the framework; 2) seven insights about how students' frame their decision making, surfaced by difficulties encountered in applying the framework; and 3) five strategies the students use to seek information. We conclude that DSA holds promise as a framework from which to develop a bridging language. However, future work is needed to investigate the feasibility of applying it in real time as a reflective tool. We also suggest a number of implications for how the lens of DSA might support students' in having stronger design rationale through development of information seeking practices.

2: Design as Decision Making

2.1 Design as Decision Making

People use metaphors to think and reason about abstract concepts and the metaphors we use affect how we understand these concepts [9]. Design is no exception. Designers' use of metaphor within the design process is extensive. However, designers and design educators also use metaphor to understand, reason, and teach about the concept of design itself and it's core ideas - problems, solutions, ideas [10]. Common metaphors in engineering include design as search [11], as decomposition [10], as problem solving [10] as a process of selection [12], as a process of exploration [13], as bricolage [14] as a journey [15], or as a process of decision making [16]–[18]

There is no one "correct" way of framing design, but the metaphors and models we hold for design affect what we see. For example "A designer who sees design as a process of selection is more likely to list options and then select between them, whereas a designer who views design as a process of exploration is more likely to generate and test a number of options, iterating towards a solution" [19, p. 286].This is of particular importance to engineering educators, as the metaphors and models we use to describe design matter for how our students develop understandings of design. In developing a "***bridging language***" to support students in capturing and making sense of informal experiences, the choice of metaphor or model matters. In our previous work, [20] we find that students do not feel they are designers, or that their academic makerspace supports design. However, they do identify with decision making and document decision making in their process. As such, we choose design as decision making as a framework for developing a bridging language.

It is universally agreed that designers make decisions throughout the design process [1] Decision making is well studied outside of design resulting in two major models: rational decision making (RDM)[21] and naturalistic decision making (NDM) [22]. There are a number of design decision making frameworks based on RDM that treat design as a rational process of choosing among design alternatives [16]–[18]. While most models of design decision making are built on the RDM, Zannier and colleagues find that software engineers use aspects of both RDM and NDM concurrently[23]. Another area of study in design decision making is design rationale [8], [22],

[24], [25]. Design rationale focuses on facilitating learning through the documentation of design decisions and their justification.

2.2 Design Space Analysis

We use the Design Space Analysis (DSA), a design rationale methodology, as a framework and notation system for this study. This framework was selected because it was designed as a reflective tool for designers to engage with and understand their own process as well as communicate their process and rationale to others. This positioning as a reflective tool holds promise in the context of developing a ***"bridging language"*** to support students in reflecting on their own informal design process. DSA is a framework for representing the design rationale for designed artifacts [26, p. 720]. The motivation for DSA is to make explicit, not just the final decisions made in the design of an artifact, but the rationale for why these decisions were made [27]. It offers an explicit notation system to help designers 1) reflexively engage with design and 2) use as a communication tool to help both the designer as well as serve as a trace that is meaningful for other designers or stakeholders. We briefly outline the key features of DSA used in our study. A more in-depth account can be found elsewhere [26]–[28]

Design Space: The DSA framework aims to explicitly describe and represent the design space around the artifact being produced [28, p. 214] rather than just the specific artifact. Design space includes both a decision space - which "describes what the components of the finished artifact might be" [27, p. 247] and an evaluation space which "describes why the choice of particular options makes sense for the design as a whole" [27, p. 247]. The artifact is characterized by the set of options that are actually selected and the alternatives and reasons for these choices provide an argument or rationale. The central premise is that seeing alternatives and not just the final decision will help designers and others reason about these decisions and thus make better decisions.

QOC notation system: A central piece of DSA is a notation system (QOC) organized around Questions - which highlight key design issues, Options - which represent alternative solutions or potential answers to these questions, and Criteria which serve as a standard against which different options are judged. The decision space is represented in the notation by options which are organized around design questions and the evaluation space is represented by criteria and [8], [27], [28]. The notation system is semi-formal and allows for explicit representation so that designers might reason and communicate about their rationale.

3: Method and Setting

3.1 Setting and Data

This study analyzes the experiences of a group of undergraduate students participated in material inquiry in a university makerspace at a large public university over a ten-week quarter. Seven students enrolled in a 2 credit course where they 1) engaged in a sewing project of their choosing through self-directed learning, 2) individually documented their project process through field notes and reflection entries, and 3) collectively discussed and analyzed their experience through discussions, open coding, and the creation of activity timelines in weekly group meeting.

While the students were asked to work on one project throughout the quarter, they engaged in a number of projects. These projects involved making e-textiles (light-up gloves and light-up beanbags), garments (shirts, skirts, and dresses), and accessories (pillow case, handkerchief, and reusable menstrual pad). Students produced a number of traces of their project activity. After analysis of student reflections, decision making was identified as an activity that students identified with [20]. In this work, we focus on their field notes. During project engagement, students produced autoethnographic written entries describing their actions and experience.

3.2 Analysis

The first author facilitated the material inquiry group, conducted preliminary qualitative analysis of all student's field notes, and conducted a preliminary application of DSA to one field note as a proof of concept.

Then, a team of 6 researchers used iterative qualitative analysis to apply the DSA framework to the student's field notes. Several approaches were used, considering tradeoffs of applying the framework in different ways and triangulating to increase the robustness of results. The team began applying DSA to all of the field note documentation of one student. Due to the breadth of questions (key parameters) present, it was decided that more coherence would be seen by looking across the 6 students' notes on a similar subject. Decisions around sourcing and acquiring materials and tools was identified as an area of similarity across the student's experiences and a sub selection of field notes were identified by the first author. These field notes were analyzed to determine the material decisions negotiated by each student. All field notes were reviewed and text for each decision was compiled across the duration of student projects.

Constant comparison across students and their different material decisions was used to generate categories of questions that could be consistently applied across all decisions. QOC diagrams were generated linking options and criteria to these questions. The researchers synthesized options and criteria across all questions. These categories of questions and insights about students' use of questions, options, and criteria are summarized in section 4.

Memos and themes were generated from what made DSA difficult to apply throughout the process resulting in seven insights about student's decision making described in section 5.

While applying the DSA framework, it became apparent that how students determined the questions, options, and criteria to consider could be of great importance to their resulting rationale. A subsequent analysis performed by the first author used grounded qualitative analysis to generate memos and themes focused on how students sought information to make material decisions. Six resulting information strategies and how they relate to the DSA framework and student's rationale are detailed in section 6.

4: Making Design Decisions Visible

All students make design decisions: Through the DSA framework, we identified design decisions by looking for a choice between divergent options and rationale for that choice. Based on this, all six students in our study made many design decisions related to material choice throughout the ten weeks of working on their projects. A number of commonalities were found in the student's decision and rationale space (options, questions, and criteria) across projects. While present, students' scope of design considerations (questions) and rationale is limited.

Questions: In the DSA framework, questions represent key design issues. We identified four categories of questions. Students consider 1) what materials to use (material choice). As part of this decision, they also consider 2) how to get those materials (material acquisition), 3) what to do next (order of operation), and 4) how to get information to make these decisions (information seeking). For the first two categories we identified 8 sub-categories detailed in table 1 below. While students do consider design issues related to material choice, the scope of their decisions is very narrow.

Categories	Sub Categories
Material Choice *What Materials and Tools to Use*	Do I make or buy the material? What quantity and/or size of material to buy? What color of material to buy? What kind of material to buy
Material Acquisition *How to Acquire Materials and Tools*	Where do I get materials When do I get materials How do I get there (for physical stores) Who do I go with (for physical stores)
Order of Operation What to do Next?	
Information Seeking How to get Information to Make Decisions?	

Table 1: Categories and Subcategories of questions.

Options: In the DSA framework, options represent design alternatives. Students do not often explore many alternatives. They are typically given one answer from their tutorial. We see them exploring small spaces of options when they encounter a number of slightly different materials (such as different kinds of elastic, or different colors of EL wire) while shopping for materials. We do not see any student's report on ideation type activities to generate options.

Criteria: In the DSA framework, criteria are the standard against which different options are judged. The students in this study do consider criteria in their material decisions. However, the criteria mentioned are limited in scope and do not reflect the kinds of criteria an expert might consider or we might teach in an engineering design course. Common criteria include aesthetic considerations, low cost, time, availability, convenience, and familiarity.

Rationale: In the DSA framework, rationale is students' reasoning for choosing an option based on the connections between that option and the criteria of interest. Often a student's design rationale for a particular decision is limited, they do not explore many connections between criteria and options and instead typically choose an option recommended by an expert or the tutorial they are following. Student's seem to articulate more rationale for things like color choice than type of material for example.

5: What we learn by trying to apply QOC

Through using the DSA framework to look at students self-directed making experiences, we found a number of complexities in the application of this method that brought to light interesting insights about student decision making behaviors. These complexities are things that need to be addressed by the framework if it is to be used as a ***"bridging language."*** They also provide preliminary knowledge as to how students are making decisions in self-directed making contexts.

Standardized Questions: For the very narrow material and tool decisions expressed by students, we were able to generate common questions (design issues or parameters) seen in the previous section. However, these question types were not immediately evident and required constant comparison across many instances of decision making. This might suggest that student's think about the key design dimensions in different ways.

Dependencies: When negotiating design questions, students sometimes mention dependencies on other questions that make the current decision difficult to make. For example, when dealing with the question of quantity of fabric, Lindsey is not sure how much to buy because she doesn't know how many bean bags she is going to make. "So I don't know how successful I'm going to be with these bean bags yet, which means I'm not sure about how much material to buy". Because she has not decided how many bean bags she will make, she has trouble deciding how much material to buy.

Consequent Questions: Another complexity we noticed are "consequent questions" [27]. Consequent questions are additional questions that arise once a decision has been made about one question. One example of this is Tom's material decisions around choosing LEDs for his light up gloves. In the tutorial for his project, it is suggested that sewable LEDs be fabricated from conductive metal beads and LEDs. As the tutorial does not provide a part number, Tom seeks other options and finds that he can buy prefabricated sewable LEDs. Thus Tom first considers whether to buy prefabricated sewable LEDs or create his own. He is able to find part recommendations to create his own and does not like the aesthetic of the prefabricated ones, so he decides to make his own. Once he decides this, he mentions consequential questions such as what kinds of materials he needs and when, where, and what to buy.

Compound Questions: Two common questions that students encounter when making material decisions are "where do I buy the material" and "when do I buy the material" (see previous section for more details). At times these questions are asked independently, while at other times they are asked as one compound question. For example, from Lindsey's field notes, it appears that she views these two questions as a compound question when deciding what velcro to buy. When considering the purchase of batteries, she negotiates in a similar way - considering the quantity of batteries, when to buy them, and where to buy them in parallel.

Re-negotiation: Another element that added complexity to our application of DSA was that decisions are re-negotiated over time. Some decisions are made multiple times for different physical objects, such as a prototype and final product. Some decisions are re-negotiated when new information is found. For example, while Maddie is at the fabric store picking out a fabric for her dress, she makes a decision as to what fabric to purchase and then changes her mind. Tom originally decides to knit his own gloves which leads to a number of material decisions. Once he reads the tutorial, he realizes that using store bought gloves is an option but still wishes to make his own. He later ends up prototyping using a pair of disposable rubber gloves. Eventually, he buys and uses a pair of store bought knit gloves. The question of what kind of glove to use is negotiated many times throughout the process.

Delaying: Another time related complexity is that students consider a question, but delay choosing an option until a later point. Lindsey for example, when ordering materials on the Adafruit website, mentions that she is going to "focus on figuring out what" is needed "from the Adafruit website now" and will "get the rest later". When considering what velcro to purchase while at the fabric store, she decides to get the velcro later because she is not sure what to get and because the velcro is not immediately needed. When Maddie is looking for buttons for her dress, she decides to buy a "grab-bag" of many buttons of "all kinds of sizes and shapes" so that which ones to use can be decided later.

Weighting of Options: When considering questions, students sometimes determine that some questions are more important than others. For example when considering the question of quantity, Lindsey mentions "I'm not worried about the el wire, it looks like there should definitely be enough for as many bean bags as I want to make". However, when considering this question for fabric, she consults many tutorials to make sure she knows how much to buy. In addition to questions, criteria are sometimes more or less important than others. For example when thinking about the expense of the parts, Lindsey mentions "This'll definitely be a bit expensive, but it's worth it for me to make these and get the chance to combine some of the skills I've learned" While the project does not fit her criteria of inexpensive, she decides that the criteria of learning is more important.

6: Information Seeking Strategies

The student's in this study are engaging in self-directed project work in a domain where they are novices. As such, where and how they get information can have a profound impact on their ability to make decisions. In using the DSA framework to make visible students' design decisions, we found their information seeking behavior to be relevant to investigation of the framework as a potential bridging language. We point out 4 information seeking strategies identified in students' material and tool decisions and how these strategies support different elements of the design rationale framework.

Asking Experts: One information seeking strategy that many students describe using is asking experts. This includes asking makerspace staff or store employees as well as consulting tutorials or other online instructional resources. For example, Maria asks a student staff member in the makerspace for help picking out the right kind of fusible interfacing for her patched hankie project. When we see students ask experts for information, answers typically consist of one option and very little rationale as to why this option might be a good choice for that student's particular situation. While this strategy could lead to good decisions, it does not necessarily not help the student see a space of options and criteria from which to generate a rationale that fits their situation. In the case of the Maria mentioned above, once she arrives at the store she has trouble deciding what product to purchase. The specific name of the product (option) written down by the expert does not specifically match the options at the store. Maria mentions trouble “differentiating” the different options she sees and does not understand the underlying parameters and criteria that would help her make a decision. She ends up buying both.

Seeking Common Solutions: Another frequent information seeking strategy reported by students is to look at what is “commonly” done by others. Usually this takes the form of searching tutorials online for what options (solutions) to a particular question (design problem) others have chosen. Unlike asking experts, where students look at one person’s option, this strategy involves looking at many people's decisions to determine what a common solution is. For example Lindsey mentions searching several tutorials to determine what size to make her bean bags. She decides on 7” x 7” because she has seen it in a few “couple of places”. Tiffany describes searching many tutorials to determine what kind of elastic and fabric to use, as well as other parameters. Like asking experts, this strategy provides students with an option that will likely be a good solution without them having to consider or negotiate criteria. However, it does open up a slightly larger space of options from which students can begin to consider tradeoffs. In the case of Tiffany mentioned above, after making several iterations of her project (hair scrunchies) she determines that she did not like the common solution for elastic and would have made a different choice - “All of the tutorials told me to use the flat elastic that was a bit wide. In the end, i did not like how it looked/felt when i wore my scrunchies since it was just too wide and restricting. I actually wish i got the skinnier elastic”

***Browsing*:** Student’s describe a behavior that they call “browsing” where they seek information by gathering options to choose from through visual inspection. This is particularly prominent when searching for what to purchase at a store or online. Nearly all of the students use this technique in their trips to physical stores to acquire materials. For example, Maddie mentions “I do a quick 2-minute walk through of the store just to get a sense of where and what everything is”. Other students mention walking through the aisles of physical stores or looking up more options on websites at home or while they are in the fabric store. This browsing behavior can be seen as an explicit search for options to choose from. The opening up of many options is essential for decision making.

Following this search for options, many students use sensory inspection to determine relationships between options and criteria. For example, when Tom is looking at yarn he describes the color 'blueberry blue” and the size “size of a small butternut squash” and that it is incredibly soft. But he is unsure if it will work for knitting gloves. He mentions that his tutorial suggests “worsted weight” yarn, but that it “just looks like yarn”. He does not mention looking at the weight of the yarn, or considering other functional characteristics like how washable the yarn might be, or how easy to knit with. In many cases this sensory inspection does not lead students to consider criteria that might be seen as important to the functionality of their projects. Compared to asking experts, which often presents only one option, browsing opens up a space of more options. However, the criteria that students use to assess these options if often limited to sensory information that is not always most relevant to the functional success of their project

Modeling: Something we see very infrequently in the student’s documentation is modeling as a means of information seeking. We see at least one example of what can be described as modeling from Maddie. When picking out fabric, she uses the strategy of visually modeling in her head what she thinks her fabric choice will look like. She has picked out an “orange-y rust colored flannel fabric", but once she starts walking toward the cutting counter she changes her mind. She had "envisioned a business-y hipster style skirt" and realized that the "fabric would give the skirt a grunge look". This is an example where Maddie is relating specific options to criteria that are unique and important to her. In this case modeling supports more authentic design rationale than some of the other cases of information seeking.

Testing: While not an explicit early information seeking strategy, a few students test or intend to test multiple material options. Maria is unable to determine which fusible interfacing is appropriate at the store so she purchases both. While many of the students only create one product, Tiffany makes many iterations of hair scrunchies in different dimensions and materials. She mentions how the making of many versions gave her information (options, criteria, and relationships between them) that would have changed her decisions. *"A lot of the tutorials suggested that i use the 100% cotton fabric, so i bought a ton of fabric quarters. I also stumbled across the cheap scrap fabric at Joann and found a cool plaid pattern that i loved. But it was a rayon material so i was scared if[that] it wouldn't work to make a hair scrunchie (since none of the tutorials said anything about rayon). In the end, i surprisingly actually liked the scrunchies made out of the rayon fabric the most since it was a lot softer than the fabric fat quarters. And i actually regretted buying so much of the fat quarters."* In this case, experimentation with many options allowed Tiffany to assess criteria option relationships and determine for her particular context a rationale for particular material choices.

7: Discussion

This analysis concerns the potential of the design space analysis (DSA) framework [8] to aid in developing a bridging language - a practice enabling students to self-document and reflect on design experiences across formal and informal contexts. 6 students engaged in independent self-directed projects over a 10-week period in an academic makerspace. During that time, they self-documented their project experiences through written field notes. A team of 6 researchers analyzed material decisions described in students' field notes through the lens of Design Space Analysis (DSA) This framework links divergent questions representing key design issues, options representing design alternatives, and criteria used to evaluate the alternatives. Results of the analysis are that 1) students make a number of material decisions, but their rationale is limited in scope, 2) the complexity of applying DSA surfaced 7 insights about how students' frame their decision making, and 3) how students search for information is an important aspect of their decision making.

7.1 Using DSA as a bridging language

DSA holds promise as a framework for developing a bridging language. In this informal sdPBL context, the framework made visible students' design rationale for many decisions around material choice throughout their process. Preliminary examination suggests that this is true for many decisions outside of the context of material choice as well. Without the framework, it was easy to see that the students were making narrow and fairly uninformed decisions. However, applying the framework made clear 1) that students were making many decisions throughout their process, 2) using rational and 3) where there are specific areas for growth in this rationale.

It was difficult for the students to see design in their experiences [20]. However, decision making and the rationale for these decisions was a process they naturally documented. These students were asked only to engage in a project in the makerspace. They were not asked to design, nor were they asked to document decision making as part of their experience. Given this, it is likely that this framework might apply broadly to informal sdPBL experiences.

Given that DSA made design rationale visible, we raise questions about how students might use this framework to document and reflect on their process in informal settings. In our analysis, we were able to generate a common list of questions (design issues) that student's were negotiating (section 4) through constant comparison across the student's experiences. This suggests that students' have common kinds of design questions, but wrote about them in different ways. To increase the likelihood that students are able to make sense of their process across experiences, a library of common questions, options, and criteria might need to be developed for students to use as reference.

While the language of DSA does provide a means of seeing design decision making in maker experiences, there are a number of areas that need to be further studied to analyze and develop it applicability for students as a bridging language. It was not lightweight to apply. The capture of field notes and analysis of all decisions through the framework is likely too time consuming for students to apply to informal design experiences in situ. Determining strategies for selecting decisions to unpack is an area of future work. In addition to the notion of tracing questions, options, and criteria, we noted the importance of information seeking. Accordingly we recommend the tracing where the knowledge of these elements came from as part of this documentation practice. Finally, the framework was not used in a formal engineering scenario. While we expect it will be applicable in formal design education contexts as it was generated for professional design setting, this is yet to be tested. Therefore, how researchers, educators, or students might use DSA to promote design reflection is an open question for future investigation.

7.2 Implications of what DSA Made Visible

DSA made visible the limited scope of students' design rationale as well some limitations of their means of seeking information (questions, options, and criteria) to form that rationale. Given that the students were novices with limited domain knowledge, this is not surprising. However, it raises the questions of how DSA lens might help students strengthen their design reasoning in unfamiliar domains.

Tutorials: All of the students in our study use DIY tutorials or instruction sets as a resource for making. DIY tutorials are widely used in the maker community as evidenced through platforms like Instructables. The students describe choosing these instruction sets as a means of offloading decisions [20] to someone with more knowledge. However, through the lens of DSA, we see tutorials as narrowing the decision space, not offloading choice completely. Student's still end up making minor decisions about materials specified in tutorials.

While most tutorials give one option for a particular question (design issue) and limited criteria or rationale, some tutorials do present a space of options. For example, Lindsey's tutorial for glow in the dark bean bags suggests two options for closing the bean bag; 1) sewing it shut, and 2) using velcro. Lindsey negotiates the tradeoffs between these two options, and chooses to use velcro so that her bags can be reopened in the future. After this she then moves onto the level of decision that most students are dealing with - what kind of velcro to buy and where, when, and how to buy it. It's not clear if she would have seen this as a decision point without the tutorial pointing it out, but it does bring up an interesting question about how tutorials might help us students see questions, options, and criteria. One thing we find missing from many tutorials is rationale for the choices made, or even that the suggested procedure is the results of the tutorial authors decisions. We note examining how tutorials might be redesigned to support design rationale as an area for future work.

Browsing: Another common information seeking strategy that students utilized was browsing. Preliminary analysis suggests that student's use this strategy outside of material choice in other decisions such as looking for projects and tutorials. In contrast to asking experts, which often presents one option, browsing opened up a space of options (alternatives) for students to choose from. If students are not able to see any options there is no chance for them to develop rationale. However just seeing options is likely not enough. Student's will need to be aware of criteria as well. In the case of browsing for options, students often only negotiated between surface level criteria that were the result of what could be determined through visual inspection. For example, when Tom is picking out LEDs, the exact component suggested by the tutorial is out of stock. He browses the electronics website for an alternative. His rationale for choosing is that "they cost the same for the same amount and they look the same from the surface" FN7. He does not mention considering electronic characteristics such as resistance or power that would likely be very important to the circuitry design. An area of future work is the examination of other strategies that might help students be more aware of functional criteria that are not easily visually apparent by browsing options.

Calculating : Something we found surprising, was that when dealing with questions of material quantity, students do not mention calculating as a means of gathering information. Instead they choose to ask experts (via tutorials) or look for common solutions. Lindsey, for example, is making several bean bags for which she must buy a certain amount of canvas duck cloth. She mentions that the tutorial she has been using lacks this information and she consulted several other tutorials. We might ask, why didn't she just calculate how much fabric to purchase? Lindsey had the size of the bean bags, and could have determined the width of the fabric. With simple geometry, which she presumably learned in her schooling, she could have estimated how much fabric she needed. We see a similar behavior with other students and other materials. This is a case where a student does not transfer a technical skill from formal learning into their making. Future work is needed investigating how we might support student's in applying certain technical skills from formal education in their design decision making in informal settings.

8: Concluding Thoughts

Documenting and reflecting on one's own design process is difficult, especially in informal contexts. DSA holds promise as a framework for developing a ***"bridging language"*** that might help students connect formal engineering concepts to ongoing informal practice through documenting and reflecting on those experiences. While there is still much work to be done investigating the implementation and effectiveness of such a ***"bridging language",*** using DSA allowed us to see design in students "making" experiences - We see explicit areas where we can draw student's attention to concepts like criteria, divergence, and tradeoffs. We also identify many areas where we can help support more rigorous design rationale, particularly through student's information seeking practices.

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