What Gaze Data Reveal About Material Agency

Resilient makers, materials and ideas

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ABSTRACT

As designers and makers work with materials, the materials may "talk back." Some have characterized this as a conversation with materials, and others as material agency. Using interaction analysis of gaze data collected in a university creativity and maker course, we characterize forms of agency displayed by maker and materials to understand resilient work. Two students—one with extensive experience with some of the materials, and the other with no prior experience—wore eye tracking sets during an in class activity to create a light with a switch using LEGO pieces, copper tape, a coil cell battery, and LEDs. We identified material interviews and trust building as common interactions. When makers pursued ideas that misfit with their materials, we gained insight into their own forms of resilience.

CCS CONCEPTS

• Interaction design • Field studies• Design patterns

KEYWORDS

LEGO, Eye-tracking data, Maker, Interaction analysis

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1 Introduction and research purpose

Research on making and makerspaces has focused on roles making might play in a range of learning and education goals, from supporting persistence of diverse students, understanding how makers collaborate and learn in this process [1], and building students' interest, capacity, and persistence, especially in STEM. Such research suggests that making can positively impact creativity [2] by encouraging curiosity and open-ended investigation, leading to deep, meaningful knowledge construction [3]. Taken with these findings, the nature of making—a highly material endeavor—also makes it a promising means to study how learners display and share agency *with* materials. Typically, agency is characterized as making decisions, and originally was characterized as a highly individual activity [4], sometimes influenced by whether they situation permitted the individual to act [5]. Scholars have expanded this idea to characterize agency as something "extends beyond the skin" [6] and that may be shared with other individuals [7, 8]. More recent post-humanist approaches have also assigned agency to materials [9, 10].

We build on this foundation by also drawing from the notion that design is a conversation with materials [11]. In doing so, we sought to build understanding of material agency as it unfolds and across designer-material pairings, an area that has not been well-studied. The purpose of this study was to elucidate material agency as revealed in different data sources, across designers with differing familiarity with materials, guided by research questions:

- What kinds of agency negotiations occur between materials and designers with differing familiarities with the materials?
- How might resilience—of materials, makers, and ideas—shape agency negotiations and reveal framing agency?

1.1 Fostering agency to direct creative problem framing

We situate our work as constructionist [12]. Papert [13] raised concerns about overemphasis on teaching and lack of attention to the process of learning—a subtle process that takes time as learners get to know and talk about the problem, and take the time to engage with the problem—centering the importance of resilience. In our work, though learners are building circuits, our focus is not on whether they develop understanding of circuits and related science, but rather that they develop their own creative problem framing skills. To support this kind of learning as constructionist, we emphasize that time, space and reflection are central to resilient progress. We likewise emphasize learner agency to produce knowledge by using their own ways to engage.

Making and designing present many opportunities to foster such learning. For instance, Tan [3] found that when students were given a high degree of autonomy in solving authentic problems in a makerspace, they pushed boundaries and learned from their mistakes. Supporting learners' sense of control over realistic problems can increase their perception of the usefulness of their work and lead them to pursue it with more effort and persistence

[14, 15]. Interest-driven making can shift learners' perception to feel their learning is personally relevant [16]. It can also give them a sense of ownership over their work [17].

To focus on this sense of ownership, we consider a context-specific approach to agency, much like others have treated self-efficacy (e.g., science self-efficacy, mathematics self-efficacy). Here, we consider how participants and materials display agency to frame (and reframe) a problem by making decisions that are consequential. Termed *framing agency* [18], this situated approach provides a lens into how problems are shaped—in this case, by both designer and materials.

1.2 Materials have agency, and some are resilient

Building on the notion of design as a conversation with materials [11], recent research has begun to explore materials as having agency, as *actively participating* in the process [19]. Yet, this area is under-theorized, so to make progress, we co-opt three terms developed to describe material properties. Manzini and Cau [20] proposed that *being* materials are traditional raw materials like glass, wood, and clay, which have well-known material properties. Inspired by this, we define *being* materials as those that exert covert influence or are treated as backdrop. Being material conversations involve treating the materials as well known, literal, and not improvable or repurposable. When resilient, they maintain their form. In this study, we consider several materials, including LEGOs, which commonly function as a being material. LEGO bricks can be coercive in telling designers how they are supposed to be in a design, studs facing up and securely linked (Figure 1). Such materials exercise high agency over designers and makers.

Manzini and Cau [20] characterized *doing* materials as engineered materials, like composites, as they were designed for specific applications. We define it as materials that are selected specifically to do something in a design. They meet a need and this is negotiated between material and maker. When resilient, they maintain their function. Less common LEGO pieces, like hinges, are doing materials selected to function in a particular manner. However, makers may interview materials to uncover possible functions. For instance, a LEGO plate turned on its edge may be wedged between the studs of another. While this function is certainly designed into LEGOs, most overlook this technique, as if the pieces only share this capacity with a few makers. In doing material conversations, both the materials and makers have agency, but it may not necessarily be shared. We might characterize such conversations as makers asking, "Can you do this?" and materials answering "I can" or "I cannot."

Bergström, Clark, Frigo, Mazé, Redström and Vallgårda [21] argued that modern advances in material science have resulted in *becoming* materials, like smart and nanomaterials, that change over time in intended ways. We define this term as agentive repurposing of materials that unfolds interactionally. Such material conversations lead to transformed material. When resilient, becoming materials retain their capacity to adapt. For instance, a becoming material conversation with LEGOs might result in alterations, like drilling a hole, slicing the studs off, or gluing googly eyes onto them. These reconfigure the materials in ways that the materials themselves may be considered remade, designs in and of themselves. In such material conversations, agency is shared and negotiated between the maker and material.

In the process of making, we may see shifts from being, doing or becoming material conversations as makers listen to and learn from materials. Yet, repeated experiences with a material can build expectations that it should only *be* a particular way or *do* a certain function. We are particularly interested in how making can foster capacity to engage in becoming materials conversations, even when working with being and doing materials that seem particularly resilient.

Individuals see different affordances in the same materials based in their own experiences and interests [11], including their everyday and cultural experiences [22]. Likewise, when designers have a nascent understanding of the materials, their initial ideas tend to have low correspondence with their final designs [23]. As they develop familiarity with the materials, their understanding of material affordances shifts [24].

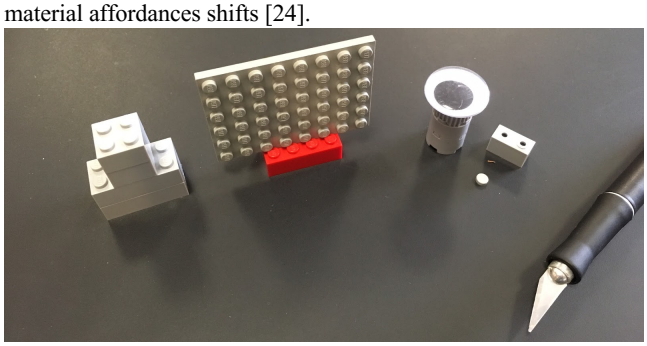

Figure 1. LEGO bricks as being, doing, and becoming materials

2 Methodology

As part of a larger design-based research [25] study on how maker activities might foster creative strategy use and framing agency, we selected cases to investigate how makers share agency with materials.

2.1 Participants & course design

We conducted a study in a joint undergraduate/master level creativity and technical design course. The course focuses on replacing myths of innate creativity with research-based strategies that students practice to enhance their creative problem framing. The course is hybrid, with an online component and a 75 minute lab.

To set course expectations, the first lab involves making name boxes using upcycling. The boxes jointly allow students to keep track of small project work and make it easy for guests to refer to students by name. By design, it is also a reason to have hobby knives and glue on the tables; while we clear away the upcycling materials and replace them with small bags of LEGO pieces, we leave knives and glue available. Students are then tasked with coming up with as many ways as they can to change the directions of the studs. Each bag contains an unusual array of hinges, Technic™ pieces, and bricks, therefore presenting many ways to

accomplish the task. After 20 minutes, the instructor quietly walks around the room, slicing studs off LEGOs and gluing them onto others. She guides a discussion about the nature of material agency and creativity.

Two weeks later, as students have begun learning about research on creativity and reflecting on their own creative process, they complete a prelab to exploring ways pieces can fit together. Using Swooshable (https://swooshable.com/snot), they are asked to review three techniques and be ready to help a classmate with such a technique. They make a LEGO-style manual that shows the build process with at least 6 pieces and at least 3 steps. The purpose of this was seed the idea of documenting process

During the lab, students used LEGOs, copper tape, LEDs, and coin cell batteries to "light up some LEGOs" with the following design requirements: it must (1) have a switch that turns the light on and off; (2) only use the supplies on hand (scissors, copper tape, wire, scotch/masking tape, LEGOs, LEDs, coin cell batteries). Because most students had no prior experience making a circuit, the instructor provided a partially complete circuit on their workspace with copper tape and a battery already attached to a mat, and questions to prompt their exploration: Does it matter which way the battery or LED goes? How can you tell? Students were encouraged to document their process for one of their required blogposts.

During each lab, we offered students use of head mount cameras or eye-tracking sets to document their progress for their blogs. Of those who wore eye-tracking sets, we selected two cases based on their contrasting experiences: Jessica, though very familiar with LEGOs, was apprehensive about electricity. She had some knowledge of circuits. Fabiola, who grew up in a rural community outside of the US, had never worked with LEGOs before nor built a circuit. She was initially apprehensive about documenting her process, and only after she experimented a bit with the materials did she ask to wear an eye-tracking set.

2.2 Data collection & analysis

Both students wore mobile eye-tracking sets. While there are quantitative approaches to analyzing such data, we used the video data from the world camera, which records the field of view overlain with a red dot to show gaze, yellow circles to show fixation, and red lines to show saccades (quick visual jumps). We created a time-stamped transcript of activity using InqScribe to note the onset of activities and a key to denote the participant's interactions with materials, tools, and peers.

We conducted interaction analysis [26] of this video/gaze data, attending to being, doing, and becoming materials. Compared to typical interaction analysis, we took a post-humanist turn, emphasizing material agency [27]. Specifically, we focused on a subset of interactions as follows: the structure of events (e.g., building a circuit, a switch), turn-taking driven by a physical task (e.g., who or what is "allowed" to interrupt), participation structures (e.g., who/what controls, constrains, or promotes participation), and the spatial organization of activity (e.g., who/what has access to materials, who can move objects, how is gesture used). An assumption of interaction analysis is that knowledge and action are social in origin, organization, and use, and can therefore be interpreted by researchers who identify regularities in the ways people interact with one another, artifacts, and the world. Such interactions make power dynamics visible—in our case, about maker and material agency. To bring attention to material agency we characterized forms of interaction (Table 1).

Table 1. Forms of maker-material interaction

Candidate selection	Visual search (gaze data) or dig in bin, brush pieces around in search of a being or doing material
Interview	Fixate on, pick up and consider pieces, form a pool of possible being or doing materials
Rejection	Eliminating a material from a design
Trust build	Unfamiliar materials sometimes seem to have a mind of their own, to behave in unexpected ways. Checking in for expected behavior builds trust that they will "behave." Gaze data sheds light on what the maker is attending to in trust building interactions.
Investigate with	Explore possible becoming material options, investigate new affordances. Gaze data sheds light on what the maker is attending to in these co-investigatory conversations.

3 Results

3.1 Jessica

As she began working, Jessica had a hinge in the middle of her workspace. She picked up the small bag of LEGOs from her prelab and quickly scanned the pieces. She discarded the bag and moved to the bin of LEGO pieces on the table. She interviewed several pieces—hinges, hinge pins—for their ability to open and close.
After four minutes, Jessica identified four possible solutions for the moving parts of the switch; she set these in her workspace (Figure 2).

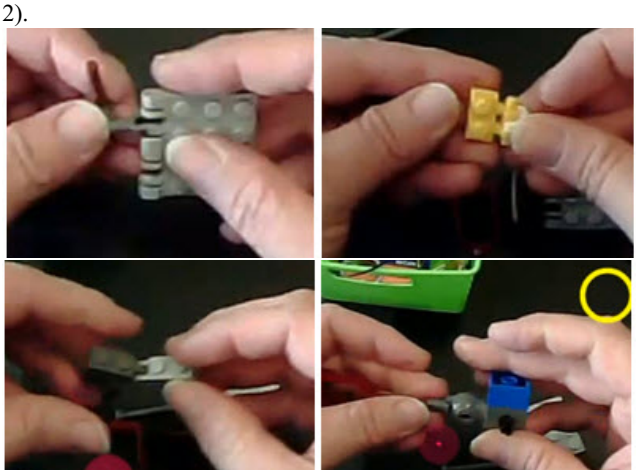

Figure 2. Jessica interviewing candidate hinges

Jessica then shifted to testing the battery and LED (building trust), placing the battery between the LED legs and pressing (Figure 3). This worked and she did not explore other configurations.

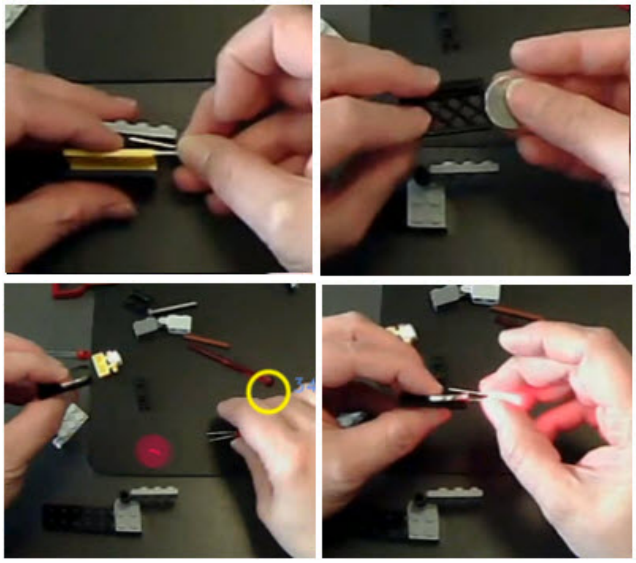

Figure 3. Jessica testing battery and LED between the static and moveable LEGO pieces.

She chose one of the hinges she had interviewed and connected it to a 2x8 brick. Together, this design stood independently. She then chose a lattice fence and used copper tape to affix it the battery. Jessica made several attempts to sandwich one LED leg between the lattice fence and the battery, ultimately using more copper tape to join all of the pieces. She connected the fence/battery/LED assemblage to the platform piece next to the hinged LEGO piece. She pressed the hinged piece to the assemblage and the LED light up. She opened the hinged piece and the LED light switched off. She turned her switch off and on several times, celebrating her creation. As she finished quickly, the instructor offered her a motor. Jessica began with an assemblage of LEGO Technic pieces (a ball joint and axle), taking advantage of the axle pieces to build onto the motor. She solved the misfit problem by wrapping copper tape around the motor shaft then slipping the axle over it. She connected the motor briefly to a battery to see if it would spin, laughing with delight as it did. She disconnected the battery and built a spinner onto the Technic base, including LEGO flower and small window frames. She built a housing, first using a large frame, but with no way for the motor leads to exit the housing, she rejected this approach and built a housing with a large plate, yellow lattice fences on two sides and a 2x2 brick. She fed the leads through a 2x2 Technic brick with a hole in it, which completed the housing. She then worked on the power unit, using copper tape as a fastener, not conductor, attaching one lead to the bottom of the battery and the battery to the base plate (Figure 4). She built her switch using hinged pieces, attaching one side to the housing, and using copper tape to affix a lead to the switch. With testing, it functioned, but the spinner spun a bit wildly, so she bolstered the housing, inserting a rod into the lattice to narrow the space. For the remaining time, she repeatedly attempted to strengthen the switch and power unit. Because she used a firm hinge, the switch detached with every press. She repeatedly reattached the lead to the switch and reaffixed the battery to the plate, as the copper tape tore easily. Although functional, the switch issue remained unresolved.

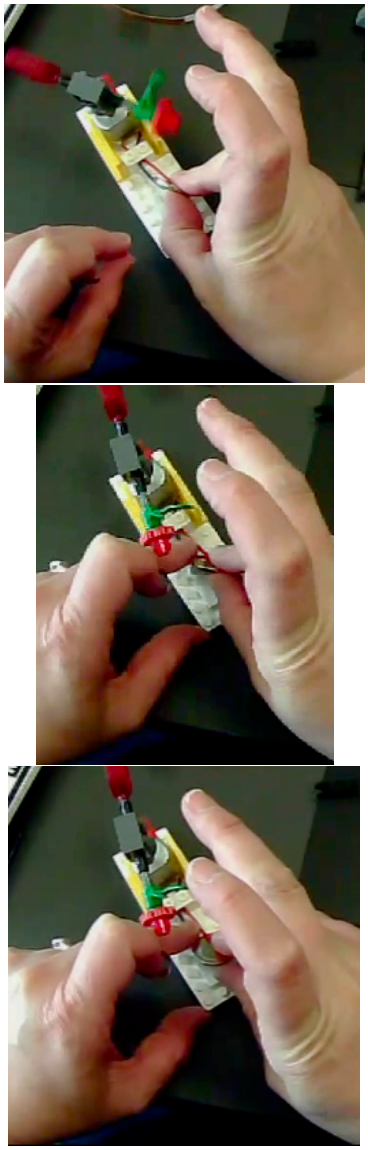

Figure 4. Jessica retained mistrust, placing the battery carefully after a successful test

3.2 Fabiola

Fabiola first built a small LEGO device to roll onto the exemplar circuit to press the LED legs onto the tape. She then asked to wear the eye-tracking while she built her own light. She began by trimming a piece of copper tape, but then she interviewed a few pieces to see if the LED might fit or attach in any way (Figure 5).

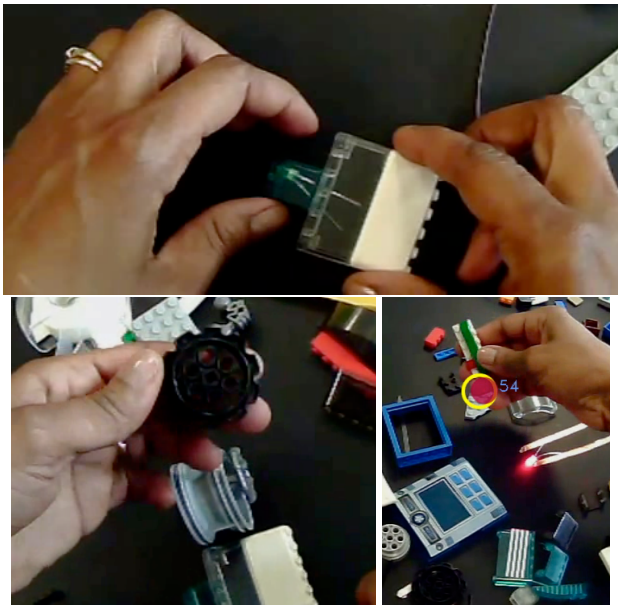

Figure 5. Fabiola interviewing pieces

She considered pieces in her prelab bag, checking for candidates to interview and selecting a hinged assembly, then scanned the table for more candidates, showing a preference for transparent pieces. She began to build her circuit, placing both legs of the LED on the positive side of the battery. When the LED did not light, she saccaded back and forth from the example to her own, then harvested the copper tape and LED from the example, suggesting mistrust of her components (Figure 6).

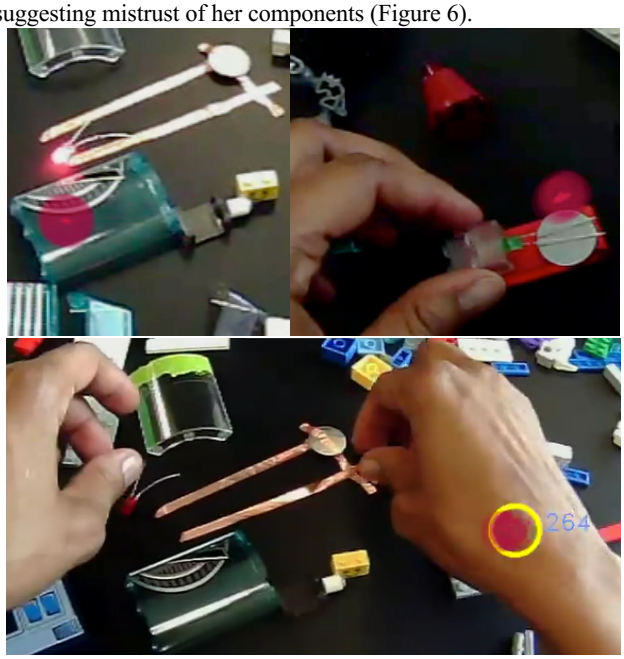

Figure 6. Fabiola saccaded to the example circuit, her own, then harvested copper tape from the example.

She recreated the example circuit onto a red door frame, and when it did not light (because copper tape from the bottom, negative side was touching the positive edge), a peer gestured to flip the LED over (Figure 7).

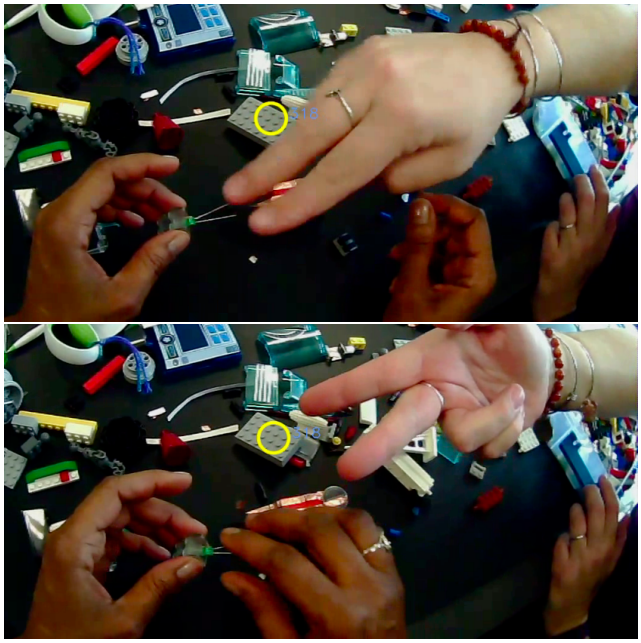

Figure 7. Peer gestured flipping the LED, with fingers as LED legs

When this was unsuccessful, she rejected the battery and identified a new one, with which she built a successful circuit (this time, the copper tape was no longer touching both sides of the battery) with a peer’s help (Figure 8). She interviewed pieces that could hinge or roll to press the LED legs onto the copper tape.

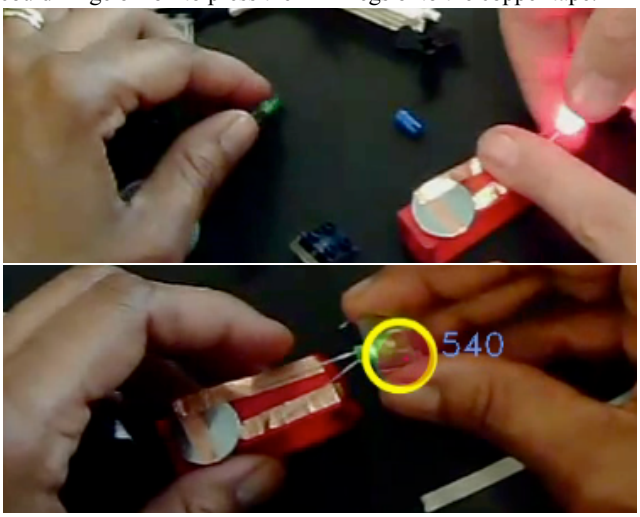

Figure 8. Peer lit red LED while Fabiola grasped green, then Fabiola built trust, testing green LED

4 Cross-case analysis & discussion

We compare and contrast the two cases, in light of our framework and organizing our analysis by materials and what this reveals about agency negotiations. First, the LEGO pieces served as both being and doing materials. When Fabiola recreated the example circuit on the smooth side of a door frame, she treated this LEGO piece as being. It was a backdrop, simply more mobile than the example on a mat. Fabiola primarily chose LEGO pieces to be somewhere and created a circuit on them. Even the switch was completed by simply placing a piece down on the LED legs to complete the circuit.

However, as Fabiola sought transparent pieces, she interviewed pieces for their capacity to do something—transmit light. As Jessica interviewed hinges, we saw her seeking a piece to *do* something specific in her light design and later in various parts of her motor design. In turn, this suggests she began with an idea—she displayed framing agency, which informed her interviews with hinges for the light and motor switch. In the latter case, the resilience of her idea, paired with the resilience of pieces that continued to function in ways that mismatched her idea—meaning, that retained their framing agency—we also see her perseverance. This led to a brief becoming conversation, as she experimented with and rejected a just-long-enough plate, attempting to bridge two studs of unequal height, after repeatedly failing to secure the switch. When this also failed, she selected a longer plate and secured it to one side, allowing it to flex and cover the slightly higher end she hoped to secure, a strategy that may have worked with additional modifications.

We were interested to see the ways in which the copper tape revealed and concealed its affordances to both women. Both primarily used it as tape, holding pieces together. Sometimes this also worked to be part of a circuit, where regular tape would have prevented completion. Often, it functioned poorly in its role as tape and by asking it to perform this role, both makers had to redo work. Jessica treated the copper tape as a becoming material when she needed a means to securely attach her spinner to the motor shaft. While she was looking for it to *do* something specific, doing so transformed the material such that it was no longer useable as tape. In re-creating the example circuit, Fabiola used it as a conductor, extending the legs of the LED. It did as it was supposed to, though we are not sure if she understood why it did so. Because of its obvious potential as tape, but rather poor tape, and lack of obviousness as a conductor, we might characterize the copper tape as a liar. Both women seemed somewhat misled by what it told them it could do.

The LEDs and batteries seem to be clear doing materials, yet using the LED leg as a switch, though not a durable solution because the material is not resilient in form, suggests a becoming approach, as it requires subtle alterations of the LED. Somewhat like the copper tape, the coin cell batteries do not speak their abilities to those who do not already know their language. Resilient in form, their edges, which conduct, produce opportunities for uncertainty.

Both students also interacted with the bags of LEGOs from their prelabs, visiting them early and returning to them several times, despite the abundance and diversity of pieces available. This suggests the more limited, more familiar pieces offered comfort, as both makers returned to their bags after interviewing and rejecting multiple pieces.

5 Conclusions

Jessica displayed framing agency as she conceived of a design and interviewed LEGO pieces about their willingness to play a role in it. More experienced with LEGOs, Jessica's idea was resilient, and in working with materials that were also resilient but misfit, we see her resilience as a maker, persisting, perhaps where revising might have been sensible. For Fabiola, the example circuit was a resilient idea. In this way, the example retained framing agency. The LEGOs likewise disagreed with this idea. Collectively, this revealed her willingness to persist in a task that was rather obscure. In both cases, the materials exerted agency in tension with each maker's ideas.

We might, therefore, characterize the maker's agency/resilience as we proposed for materials—as being, doing, or becoming resilience. In both cases, we see them pursuing function without major reframing of the problem. Given the earliness in the semester, we wonder how motivated both women were by the sense that they needed to get their lights to come on for a grade (not actually true), versus for the delight in and of itself. Had this been a much later assignment, they may have approached the task with more appreciation of process and displaying framing agency [18]. Our ongoing work will explore this aspect in later course activities and also explore what happens when students are given more time and prompts to explore options.

While much research has explored the affordances of LEGOs for learning STEM, our focus extends insights that LEGO tasks can play a role in learning design thinking techniques [28], creativity [29], even support deeper participation in learning complex professional practices [30]. Our analysis suggests that as part of a trajectory, such activities reveal much about how makers negotiate their agency with materials.

Finally, we found this form of gaze data to productively shed light on students' searching patterns and evaluation of doing materials in particular. Gaze data aided our interpretive process. While interaction analysis has more commonly focused on human-human interactions, typically relying heavily on turns of talk and consigning action-related talk as instrumental [26]. In our case, the conversations were highly material, and head-mounted video would have missed much about these conversations. Much about the candidate selection and interview process would have remained opaque (Table 1). While rejections would have been clear, and the trust-building and investigating-with conversations would have been identifiable with typical head mounted video data, the detail available in gaze data provided insight necessary for interaction analysis. Without this data, we might equate it to having transcript without tone and without speaker information. Studies like this may inform quantitative analysis by providing insight about what matters in gaze data of material conversations.

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