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Understanding Sociomaterial Encounters in Collaborative Creative Making: A Case Study from a Makerspace in India

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Abstract: Makerspaces are explored as sites for fostering collaboration and creativity, where makers share ideas, use material resources, and create meaningful artefacts. The article aims to contribute to the understanding of sociomaterial entanglements in making, which can inform the design of socio-technical spaces that promote creative outcomes. In this study, we examine how social and material encounters influence the emergence and evolution of ideas in collaborative making when novice makers engage in design problem-solving. We specifically look at data from a maker activity-centered workshop to argue the distributive nature of creative making. Our analysis suggests that social and material elements of the situated context exhibit performative roles in enabling and constraining collaborative making.

Keywords: Making, Distributed Creativity, Makerspaces, Materiality

1. Introduction

Collaborative making activities are featured by the iterative nature, encountering failures, gathering feedback from fellow makers and experts, and sometimes culminating with unexpected outcomes. Making practices bring out skills in tackling uncommon problems and constructively engaging in design (Petrich et al., 2013). Previous research studies (Bevan, 2017; Patton & Knochel, 2017; Timotheou & Ioannou, 2019) have pointed out the need to include elements of maker culture in education settings as the approach nurtures co-creation, innovative design processes, and collaboration. Hands-on makerspace environments promote maker engagement with technology, afford knowledge sharing, and encourage collaborative creative production (Halverson & Sheridan, 2014; Pandey & Srivastava, 2016). In these collaborative spaces, creativity cannot be reduced to individualistic intellect, skills, or mental processes but embedded in collaborative networks (Sawyer & Dezutter, 2009) and dialectical relation between makers and materials in social practices (Tangaard, 2013). As per this viewpoint, creative thinking is *distributed* across the interaction between people, dialog between people and objects, or interactions over time (Glăveanu, 2014; Sawyer & Dezutter, 2009). Placing design as a conversation with the situation (Schön, 1983) expands the opportunity to understand the interplay of social and material aspects in making, where makers confer with fellow makers and materials, leading to creative design prospects (Shotter, 2006). The concept of agency can be used to understand how materials 'talk back' (Schön, 1983) and influence the making processes.

Associating agency with nonhuman entities brings in the queries related to intelligence, intentionality, and purposefulness. Such divisions can be resolved with Latour's conceptualization of agency (1996), where all material entities are possible actants and actively play roles in everyday activities. Consequently, agency is not an attribute of either human or nonhuman elements but emergent manifestations and effects through certain configurations of situated entities (Suchman, 1987). Agency unfolds in practice (Pickering, 1993) and shifts depending on the assemblages of these entities. Recent works in understanding the role of materials in interaction design conceive humans and nonhuman entities as performative agents, driving the activities in design processes via interplays (Jacucci & Wagner, 2003, 2007). These reframed views on agency may expand our understanding of how creativity surfaces in maker and material conversations.

Drawing from all these prior literatures, we look into the broader research goal of how maker and material entanglements contribute towards the distributed form of creativity in makerspaces. In this paper, we investigate how sociomaterial encounters influence the emergence and evolution of ideas and designs in collaborative making, when novice makers get involved in design problem-solving. The makerspace setting considered for this study is that of a one-day maker activity-centered workshop rooted in solving design challenges attended by undergraduate mechanical engineering students. Based on the perspective of design as an inherent practice within the making process (Halverson & Sheridan, 2014; Dougherty, 2012), we consider the participants as novice makers and the process they engage in as the making process. We position the creative aspects of the making process as distributed and materially grounded phenomena (Hutchins, 1995; Glăveanu, 2014; Sawyer & Dezutter, 2009).

2. Study Details

2.1 Setting

Data for this study was collected as part of maker workshop series organized at a leading engineering institute in India. These workshops aimed to engage engineering undergraduates with Maker tools and technologies for solving design challenges situated in a typical makerspace environment. The participants of this study were second-year mechanical engineering undergraduate students who successfully completed an earlier introductory maker workshop based on Lego Mindstorms EV3 robotic kit. The workshop organizers invited these participants, to which eight students showed interest, and a total of four teams were formed in the order of their response, with each team consisting of two members. Participants were introduced to digital fabrication techniques, along with a brush-up session on Lego Mindstorms EV3 kit, as part of this workshop. All the participants were familiar with 3D modeling software like Tinkercad and Solidworks. Also, none of the participants were aware of any ideation techniques. This one-day workshop started with introductory sessions on digital fabrication involving hands-on activities with a desktop FDM 3D printer and a 3D printer pen. Later on, participants were given a design challenge: *Conceptualize an assembly line/production line that is semi-automated with static and dynamic robots. Model and build the setup with resources available in the makerspace.* The making sessions lasted for a total of five hours per team. A facilitator was present during the making sessions to support the teams in their collaborative making processes by organizing resources, such as tools and materials, and by providing conceptual and procedural expertise in events where participants were unable to determine how to proceed in solving the design challenge. This study focused on one of the student teams – Team A, consisting of one female student (G) and one male student (B).

The workshop was conducted at a makerspace with a worktable, a whiteboard, a computer, and a desktop FDM 3D printer. Each team was provided with two Lego Mindstorms EV3 kits, a 3D printer pen prototyping, 3D printing filaments, prototyping kits consisting of basic hand tools (knives, scissors, screwdrivers), cardboards marking pens, pencils, chopsticks, play-doh modeling compounds, cable ties, tapes, glue, styrofoam sheets, a box consisting of used cables, ropes, wires, paper, defective electronic devices like calculators and earphones.

2.2 Analysis

We conducted the analysis in multiple phases to explore the collaborative processes and assess the outcomes of the creative making in the makerspace. We used the SVS metrics (Shah, Smith, & Vargas-Hernandez, 2003) to assess the outcomes of the making activity. The SVS metrics acknowledge every idea that makers bring into the design stages as meaningful. As per the metrics, creative outcomes are assessed by evaluating the quantity as a measure of total number of ideas, variety as a measure of the explored solution space, quality as a measure of how close an idea satisfies the design specifications, and novelty as a measure of the infrequency of an idea compared to other ideas. As the participants in our study generated one type of idea (building robots for package movement), and since the activity did not constrain to strict design specifications, we only focused on measuring the novelty component, in line with other studies that used certain components of the SVS metrics, according to the design task (Starkey et .al, 2016; Sinha et. al, 2017). Here, novelty is measured as the infrequency of an idea compared to all the ideas presents. Following the SVS approach, idea features were identified and a genealogical tree was developed with the following levels: goal, working principle, functional unit, transfer, motion, and material details. For example, the transfer level of the tree covered the package transfer mechanism idea features incorporated in various functional units of the production line. Each idea was decomposed into the addressed features and grouped to arrive at the genealogical feature tree. The ideas were then independently rated by the author and a fellow researcher, and achieved high inter-rater reliability, Cohen's kappa = 0.893. For the idea *i*, the following equation was used to calculate the feature novelty f_{ij}, where T is the total number of ideas and C_{ij} is the total number of ideas in which the feature *j* is addressed:

$$f_{ij} = \frac{T - C_{ij}}{T}$$

The novelty score N_i, for each idea was calculated as the ratio of the sum of the feature novelties to the number of features addressed for each idea, where *n* is the number of features, z_i is 1 if the feature *i* is addressed by the idea, 0 if it is not.

$$N_i = \frac{\sum_{j=1}^{n} f_{ij}}{\sum_{j=1}^{n} z_i}$$

Once the novelty score for each idea was determined, we looked at the making process of the highest novelty score team, Team A. We began the analysis by content logging and segmenting the data into various phases of the design process such as ideating, information seeking, sketching, prototyping, testing, and refining ideas, to get an overall understanding of the making process in our context. We follow the case study methodology (Merriam, 2007) to help us unpack and follow Team A's making process. A case study is appropriate for this study due to its exploratory nature as we seek to investigate the influence of social and material elements on the creative making process and to provide an in-depth narrative. We used the content logs to conduct interaction analysis (Jordan & Henderson, 1995), focusing on talk and the use of artifacts and technologies. This analysis method is appropriate for our purpose since we use video data along with transcripts and field notes to unpack the moment-by-moment emergent actions during the group work. The idea units are considered for the unit of analysis where we look at episodes with the idea entry, evolution, and exit from the various making phases. While replaying the video and parsing the transcripts iteratively, we focus on dialogic conversations between participants along with their interaction with available material resources.

3. Findings

As per the SVS metrics (Shah, Smith, & Vargas-Hernandez, 2003), Team A scored the highest novelty score of 0.74 in the ideation phase of the making process. We followed the case of Team A's making activities and found that the team started prototyping based on the idea with the highest novelty score of 0.74, but later dropped the particular idea and then continued with another idea, which consisted of common features as that in other teams' ideas and hence with a lower novelty score of 0.56. We found that the making episodes were constitutively entangled with human and non-human elements of the situated context. We present these episodes to illustrate different instances of how ideas get shaped from primary stages to final stages and how agency emerges from the interactions between the makers and materials that influence the creative making process and outcomes. These moments do not represent the final states in the evolution of the ideas but are temporary outcomes that help refine the design ideas and making process incrementally.

3.1 Task definition

The two makers started the first design session by reading the design brief, consisting of the design challenge description printed on a sheet of paper, and began to think of possible ways of solving the design problem, as they sat at the worktable. One of the makers suggested a concept for the assembly line, where a static robot picks up a package from a conveyor belt and places it on a dynamic robot, which can be used to move the package to final delivery stations. The following excerpt shows how the makers and material resources become integral in approaching the problem.

Maker B:	So we have to build two robots. right? [pointing to design brief]
Facilitator:	Yeah.. you might be familiar with the production lines.
Maker G:	Ok.. then we need to make two robots to pick some things and place at other places
Maker B:	What could be a static robot? something kind of conveyor belt thing?
Maker G:	[moves arm with elbow fixed on the table] something like this.. picking things and placing.
Facilitator:	Yeah, kind of..
Maker B:	Then. we will use the static robot to pick from the belt and..
Maker G:	Yeah, start with the static robot.
Maker B:	.. and put the thing on the dynamic robot.. and it moves.

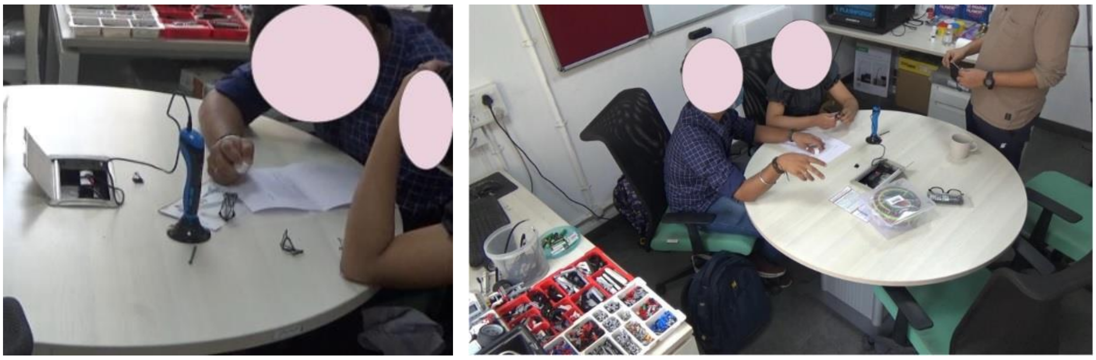

Figure 1. Team A members with the design brief and discussing the task with the facilitator.

Here the design brief is attended to by the makers and duly considered as a source for defining the task (see Figure 1). The open-ended nature of the problem in the design brief leads the makers to come up with task interpretations. The makers then consult with the facilitator to get more information about the task and develop a broad conceptualization of the assembly line with a set of imaginary conveyor belt and delivery stations. As a material resource, the design brief comes into action as the makers attend to and perform the act of setting boundaries and design possibilities of the task. Similarly, the idea exchanges between the makers and the facilitator help them arrive at a common ground for further progress.

3.2 Design Ideations

As the session progressed, the team started ideating designs for the static robot and dynamic robot according to the proposed solution approach. The makers are found to make use of the whiteboard and markers for sketching their ideas. At every step of the ideation, makers consult with the facilitator for input and to avoid conceptual errors. The following is a representative episode from an ideation phase, showing how a design idea gets shaped in the making context.

Maker B:	[Drawing sketches on the whiteboard] these are poles.. with type of belt kind of things like that of the printer and the fork can grab the object and

	move in these directions [gestures x, y, z coordinates] and height can be adjusted ..like up and down.. but am not sure how to make it
Facilitator:	Ok.. mm .. for that you will need some guider and rails or some motions like.. you might have seen this.. [takes the slide lock snap-off knife from kit].. this blade can slide over.. similar to telescopic motion.
Maker B:	So more drives.. we have three or four
Maker G:	Or may be we can suspend the fork from top.. with strings
Maker B:	Oh.. then we put strings on these poles and connect to the motors.. it can still work
Facilitator:	Yes.. think of other possibilities too.

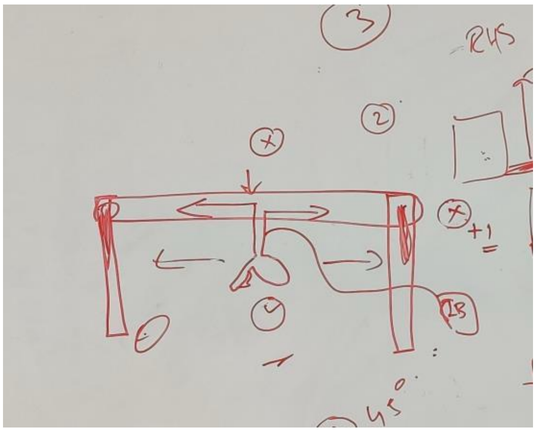

Figure 2. The sketch created by Team A for parallel robot idea.

In the above episode, makers are coming up with ideas for the static robot which can pick and place the incoming package. Maker B starts with the idea of parallel robot, Ni = 0.74, which is to be supported by rectangular frames, and with a hanging 'fork' operated using rope and pulley can pick the package (see Figure 2). The maker points out that the idea is inspired by the 3D printer conveyor movement mechanism. The facilitator pays attention to the idea and questions the mechanism to move the unit up and down, and with the help of a slide lock snap-off knife, explains the idea of telescopic motion, with guide and rails. Here the 3D printer becomes a material source that stimulates the particular idea. On the other hand, the slide lock snap-off knife becomes a source of idea narration and elaboration in the collaborative process. Similarly, the sketches are shared design artefcats, which support the collaborative idea exchange and act as anchors for negotiation.

3.3 Prototyping

As the ideas for building the static and dynamic robots were consolidated, makers started to build on those with available material resources. The team started with the idea of parallel robot, with the rope and pulley mechanism for functioning the fork. Here the makers use a variety of materials including, Lego motors, leg kit parts, chopsticks, earphone wires, play-doh, and tapes. The following excerpt shows how different maker-material configurations impact the externalization of novel ideas in terms of prototypes.

Maker B:	Do we have strings?.. can we use those filaments as strings? [referring to 3D printing filaments]
Facilitator:	Yeah.. you can try. There are some rope pieces in that box [pointing to the box with discarded items]
Maker G:	[Checks the box] there are some wires too..
Maker B:	Aah.. we can use it.. but might slide over.
Maker G:	Or maybe we can cut the ropes.
Maker B:	This earphone .. can we take that.

Facilitator:	Yes, those are junk ones.
Maker G:	[Untangles the earphones]
Maker B:	[Checks the earphones] the lower part looks ok, we can cut that.

In the prototyping session, we observed that the makers trying to blend the lego robotic kit components with mundane materials like chopsticks, earphone wires, play-doh, tapes, etc. The team members start by building the rope and pulley mechanism for the fork. The makers asked for strings (not part of the original kit) to build the mechanism. The makers and facilitator check the space for the same, but could not find the required kind of thread. But they found a box consisting of used cables, ropes, wires, paper, defective electronic devices like calculators, and earphones, and the facilitator suggested using the rope for the purpose. One of the makers identifies the possibility of using a defective earphone for the same and which is then cut and joined with lego rods for making the pulley assembly (see Figure 3). Similarly, to build the supporting structure, makers used a combination of tape, play-doh, lego motor, and chopsticks so that the fork can follow the up-down motion. Even though makers built an intermediate setup for the same (see Figure 4), it failed during testing as the components fell apart. The team members made further changes by attaching the structure to the pulley using tapes and stabilizing with play-doh, but continued to fail, which stopped them from moving with the particular idea ahead.

Figure 3. The earphone wire – lego components combination for supporting the gripper movement.

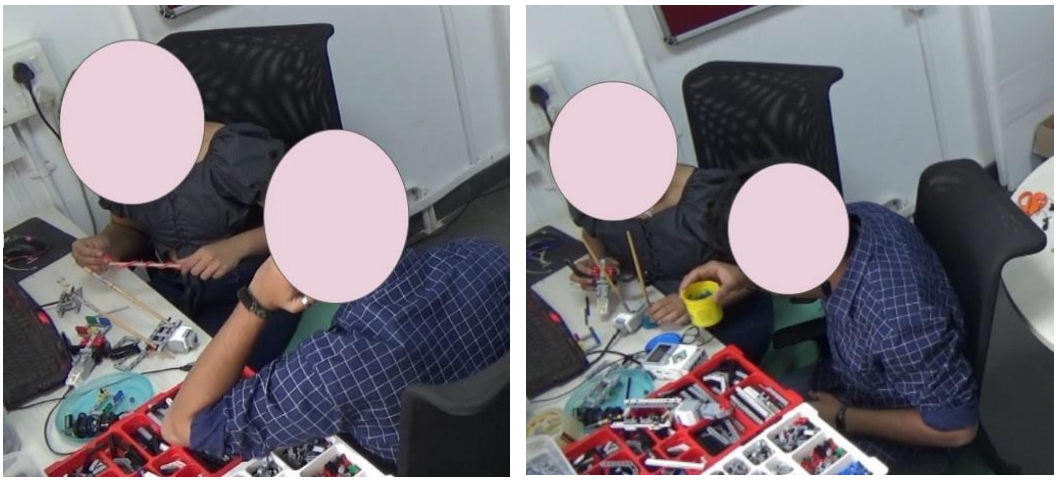

Figure 4. Team A members trying to blend the lego robotic kit components with the mundane materials for building the parallel robot.

Here, we see different modes of maker-material configurations affording and resisting the externalization of ideas in the making process. As for the rope-pulley mechanism, the perceived physical property of the earphone cable is transformed into an emergent quality of a wire-rod combination, performing the acts of fork motions. On the other hand, we find the transformed combination of lego motors, chopsticks, play-doh etc. resisting the intended actions and forcing the makers to move to alternative solution approaches.

Maker G:	I don’t think it will work.. not enough support structure.. drop?
Maker B:	Drop?.. mm .. then we will have to check the crane one.. search in YouTube.. how to build crane.. for picking up
Maker B:	[Pointing search results] got to that.. grab and lift thing
Maker G:	No.. this is something else..
Maker G:	[Opens Lego Mindstorms EV3 Classroom application] there are some models
Maker B:	Hey.. we can do that [points to serial robot model in the manual]
Maker G:	mm.. but look here [points to manual diagrams].. these got some gear systems.
Maker B:	Yeah.. but we can make these.. [picks up and shows gear parts from kit]

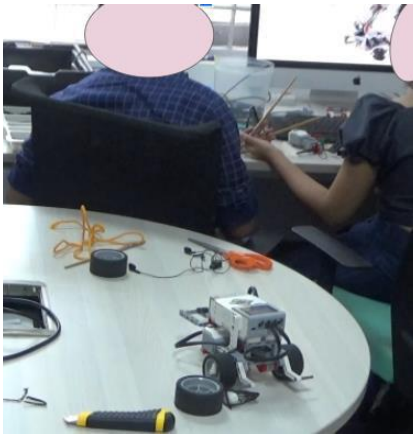

Figure 5. Team A members browsing the Lego Mindstorms EV3 Classroom manual in the computer.

As the idea of the parallel robot seemed to be difficult to realize, the team members chose to look at the other ideas of serial robots. The makers are found to search internet resources for building the serial robot and checked a few YouTube videos. In the dialogic exchanges between the makers, we can see the metaphorical use of cranes to situate the idea of serial robots. The makers agreed to continue with serial robots and, before starting, checked the Lego Mindstorms EV3 Classroom application installed on the computer (see Figure 5). They browsed through the application and found a manual for building a serial robot that can perform pick and place actions. As the makers found the similarities between the sketched serial robot idea, $N_i = 0.56$ (see Figure 6), and that of the one illustrated in the manual, they decided to follow the steps in the manual to complete the robot.

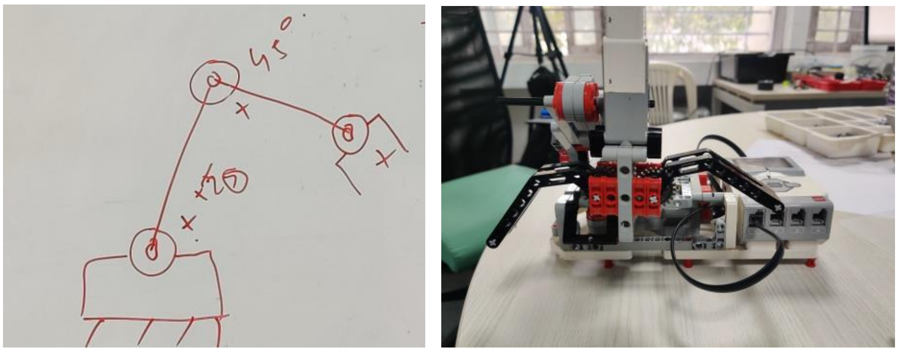

Figure 6. The sketch (left) and partially completed prototype (right) created by Team A for serial robot idea.

Here, the Lego Mindstorms EV3 manual directs the maker actions, that they are following step by step without checking the useful components of the depicted design in the manual that can be used to address the design problem. As the makers realize that one of the connecting components from the kit is missing, the making process is halted, as one of the robotic links cannot be completed. The problem is reported to the facilitator, who encourages the makers to find a way around it by creating a custom component from the available material resources. The facilitator inspects the prototype and asks a few questions regarding some of the design decisions so that the makers can proceed further without the missing connecting component (see Figure 7).

Facilitator:	Do you really need that extended arm?
Maker B:	Without that… it will not move down, with the gears connected
Facilitator:	Ok.. what if you remove that extra double frames or arm, with that connecting part? [referring to the missing part in the manual]
Maker B:	Aah.. I don't think… it will move
Maker G:	[Points to the manual sketch] not like that.. it can work, we have this motor .. [turns to Maker B] he is asking about that.

Figure 7. Team A members discussing with the facilitator, referring to the manual and partially built serial robot.

4. Discussion & Conclusion

We have presented an empirical case study of making from a makerspace in India, where novice makers engage in solving ill-structured design problems with the resources available. The case demonstrates the ways in which sociomaterial entanglements significantly shape the making paths. With the notion of agency (Latour, 1996), we examined the actions of makers and materials in arriving at creative outcomes as ideas get generated and evolved. The focus on maker-material interaction helps understand how materials play a crucial role in making and how materials "talk back" to makers (Schön, 1983), thus moving beyond the conception of materials as dormant malleable entities. Material resources like the design brief and Lego Mindstorms EV3 manual directed the makers to interpretations and design pathways, the 3D printer acted as a source of idea inspiration, tools like slide lock snap-off knife acted as a source of idea elaboration, and the sketches as anchor points for idea narration and negotiation. In the prototyping sessions, we have seen instances where makers recognize the material properties, which transform into qualities as making progress, and materials are also found to direct maker actions, provide opportunities for idea realization, and offer resistance to the making actions, suggesting the relational and emergent dynamics of agency between artifacts, tools, materials, humans (Pickering, 1993).

Team members and material resources actively contributed to dealing with the design problem, whereas the facilitator supported by providing conceptual and procedural expertise in events of impasses, hence pointing to the distributed form of creative actions (Glăveanu, 2014; Sawyer & Dezutter, 2009). We find that the agency of making gets distributed between makers and materials during the situated interactions. In this case study, we find that the distribution of agency in collaborative making is unpredictable, dynamic, and affects the subsequent creative movements. For example, Lego Mindstorms EV3 manual entry and the blending actions using Lego robotic kit components with the mundane materials are diverse and unforeseen modes of agency coming into play. We notice that maker-maker interactions, maker-facilitator interactions, and maker-material conversations opened spots for collaborative idea exchange and tinkering, which in turn facilitated and constrained the emergence of novel outcomes. On that account, while using design problem solving as an intervention or in designing learning environments, ample opportunities for social and material encounters are to be ensured to explore the potential of learning by making, especially in dynamic learning environments. With this study, we attempt to understand the emergence of creative outcomes in making by exploring the collaborative processes, maker-material interactions, and assess the outcomes of the creative making using SVS metrics, deviating from the traditional investigations on the effects of individualistic traits on creativity. However, further studies are required to expand our understanding related to the sociomaterial entanglement in creative making contexts.

5. Implications & Limitations

Along with investigating the creative actions and outcomes, the study also shows how making can serve as opportunities for learning through authentic design challenges (Peppler et al., 2016), how materials augment making, and how facilitators can support problem-solving without drastically reducing the wickedness of the design problem. The access to dense and varied material resources, ill-structured problem nature, and less scripted making sessions opened up opportunities to think and make together with materials (Keune & Peppler, 2019). Positioning creativity as a distributed action can provide insight into the distributed mode of learning in makerspace settings. This study sheds light on shared agency in maker-material interaction during making, which calls for careful design and implementation of maker tools and technologies that enact tinkerability and reflective practices (Resnick & Rosenbaum, 2013). Given the sociomaterial lens used for understanding the creative processes in the study, we suggest researchers and practitioners to expand the constructivist views on makerspace education towards the possibilities of post-human approaches (Thiel, 2015; Wohlwend et al., 2017) as it decenters the human roles, and considers other other-than-human entities into account, in learning contexts. These enlarged analyzing lenses can reveal complexities across matter and learners in sociotechnical spaces.

The present data focuses on a typical makerspace setting, where novice makers engage in solving design problems through making. So the findings cannot be generalized across other makerspace settings and sites of collaboration. Future analyses from several making contexts and among diverse makers would give a more refined understanding of the meanings of social and material encounters. It would be also interesting to see how multiple teams work in parallel to solve similar design challenges, sharing the same physical space for making.

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