Maker-Material Creative Embodiments in Collaborative Making

Alekh V*, Chandan DASGUPTA
Indian Institute of Technology, Bombay, India
*alekhv@iitb.ac.in

Abstract: Making opens up dialogic learning spaces where makers engage with the material world via embodied enactments. The article aims to contribute to the understanding of embodied sociomaterial entanglements where makers and materials encounter to form collaborative networks. In this study, we follow the encounters between makers and materials in design problem solving scenarios to uncover embodied material experiences leading to creative movements. We specifically look at a making context where novice makers collaboratively work on design problem solving, through the combined theoretical aspects of constructionism and posthumanism. Our findings suggest that the makers' embodied experiences were entangled with material elements of the situated making contexts and shaped the opportunities for learning. Makers and materials composed the embodied actions through which domain related concepts manifested.

Keywords: Making, Creativity, Materiality, Embodied Learning

1. Introduction

Making is recognized as a means to constructively engage learners in creative designs and bring out skills in tackling uncommon problems as it provides opportunities to solve real-world problems, following different ways to arrive at multiple solutions (Honey & Kanter, 2013; Martin, 2015). Learning through collaborative making involves iterative cycles of building, testing, modifying the co-inventions, and reaching common ground with the participating makers. In makerspaces individuals and groups engage in multiple forms of design activities, resulting in cross-pollination of ideas and skills (Gross & Do, 2009; Peppler & Bender, 2013; Halverson & Sheridan, 2014). The opportunity to play and engage with materials is considered to act as "a social glue" for people to converge and engage in collaborative and creative activities (Vossoughi & Bevan, 2014; Honey & Kanter, 2013; Ingold, 2013). Studies suggest that hands-on experimentation and production across different media and digital platforms support learner's creative and critical engagement in disciplinary and transversal learning (Hughes, 2017; Ratto, 2011). Makerspaces hold the potential for interdisciplinary connections, collaboration, creativity and innovation (Martinez & Stager 2013). The emergent outcomes of these collaborative networks are conceptualized to be spread across social, material, and temporal dimensions of the creative phenomenon (Glăveanu, 2014; Sawyer & Dezutter, 2009). Making being a materially grounded activity, makers and materials are in continuous entanglements, considering the theorization of "design as a conversation with the situation" (Schön, 1983). Here the makers listen to the material entities, and the material entities "talk back" to maker advancements. Such dialogic exchanges support the understanding of differences or similarities in approaching design problems among makers, learning of material characteristics, and opportunities to search through the problem and solution spaces (Shotter, 2006). Makers converse with fellow makers and materials which can result in being, doing, and becoming material conversations (Gravel & Svihla, 2021).

Being material conversations considers the materials as well-known and not improvable, whereas doing material conversations involve exploring known material affordances that can be utilized to make progress in solving a design problem. A becoming material conversation is characterized by transformed purpose, reconfigurations, and modifications of materials (Gravel & Svihla, 2021). In finding creative solutions to design problems, where makers encounter familiar and unfamiliar material elements, the being, doing, and becoming material engagements acknowledge, use, and transform the material affordance. These sociomaterial conversations can involve shared agency, which reiterates the material aspect of emergent creativity. Therefore, materials cannot be considered as dormant entities (Pickering, 1993), not only responding to the actions performed by makers but also directing the makers to creative actions. The reframed views on agency manifesting in these maker-material conversations can disrupt the longstanding human-centric explanations on learning, making, and creative practices. With Latour's conceptualization of agency and flattened ontology (1996), all material entities are possible actants and actively play roles in everyday activities. Hence, agency is neither rested solely on human nor nonhuman elements but through becoming of emergent manifestations, effects through certain configurations of situated entities (Suchman, 1987), and unfolds in practice (Pickering, 1993).

Making, especially in the context of design problem solving, celebrates the philosophies of learning by doing, failures, iterations, sharing knowledge and other resources with fellow makers (Halverson & Sheridan, 2014). In alignment with constructionism, learning is viewed to happen with the learners engaging and manipulating physical or digital materials to arrive at personally meaningful artifacts and share with the community. Constructionist ideas of "objects-to-think-with" and "body syntonicity" have been explored by the research community in understanding how learning can happen when learners engage with tangible materials. "Objects-to-think-with" can be considered as bridges that can connect abstract ideas and sensory knowledge intertwined with embedded participation and personal linkages. In terms of "body syntonicity", learning is viewed to surface as learners imagine their bodies in place and connect with the materials under manipulation (Papert, 1980, 1993). The learner's knowledge and awareness of their bodies in the learning environment can support the internalization of domain related concepts and abstract ideas.

Materials are significant in the process of learning as learners encounter a wide range of other-than-human elements in the learning environment, but the facets of these entities are not closely looked into (Engeström & Blackler, 2005). In the constructivist views of learning, humans are considered as observers and actors, whereas non-human entities are seen as malleable and controllable. Similarly in sociocultural studies, materials are seen as mediators of human practice (Sheridan et al., 2020). On the other hand, the posthumanist perspective can reveal the active ways in which digital and physical materials direct the learning process (Thiel, 2015). The notion of posthumanism looks at decentralizing humans from the sole source and center of actions and unsettling the concepts related to material neutrality (Barad, 2003, 2007; Pickering, 1993). It can bring the vitality of the matter, unpredictability, unfolding ontology, and signifies material turns as humans encounter non-human matter (Barad, 2003; Haraway, 1985). Further insights are required to understand the ways in which materials can influence learning through embodied experiences with the world.

We see the combined theoretical perspectives of constructionism and posthumanism as having immense potential to investigate the learning dynamics in rich sociotechnical spaces like makerspaces. In line with the fused theoretical approach, we follow the idea of "material syntonicty" which provides a material direction to look at the encounters between makers and materials resulting in learning opportunities (Keune, 2022). Material syntonicity points to how materials become actively engaged in the embodied intra-actions with learner bodies and provides the learners with opportunities for material ways of knowing. The analytical lens can advance the understanding the ways in which materials can influence domain learning and performing domain related concepts. Material syntonicity adds to the constructionist ideas in such a way that it reveals how materials direct embodied experiences to produce domain related phenomena. By acknowledging the active states of materials and learner bodies, material syntonicity supports further investigation into how learner experience themselves as active entities of the embodied learning process.

Based on these prior literature, we look into the broader research goal of understanding how maker and material encounters shape the emergent creativity in makerspaces. With this study, we attempt to explore *how novice makers and materials come together to shape the* *learning opportunities and creative movements in a situated collaborative making context.* We think with constructionist and posthumanist ideas to analyze the making context where seventh-grade students collaboratively work on design problem-solving. We consider design as an inherent practice within the making process (Bevan, 2017; Dougherty, 2012) and position the creative aspects of the making process as emergent (Sawyer & Dezutter, 2009; Tangaard, 2013).

2. Study details

Data for this study was collected as part of a maker workshop where two groups of seventh-grade students from an English-Medium school in the city of Mumbai, India engaged in engineering design problem. The maker workshop was organized at a leading engineering institute in India, and divided into two sessions, (1) Training session and (2) Design session. The first team-Team A- consisted of two female participants (A1 and A2) and a male participant (A3). The second team-Team B-consisted of one female participant (B1) and one male participant (B2). Teams were formed randomly and they worked on designing a cleaning robot in the design session. The design challenge given to the students is stated as: "*Keeping our surroundings clean is a very important aspect of our life but, doing that requires a lot of manual work and can get boring sometimes. Wouldn't it be amazing if a robot does that for you autonomously? Your design challenge for today is to use the Lego Mindstorm kit to build a cleaning robot. Your robot should be able to clean at least two of the following trash materials- paper bits, Lego pieces, water droplets, eraser dust, and pencil dust. You can also use the provided supplementary material i.e., cleaning mop wipes, cardboard, and sponge. The robot designs of the two teams will be compared based on how many trash items the robot can clean, how well it cleans the trash material, and the cost of the robot.*" Along with the Lego Mindstorm kit and the supplementary materials, each team was also provided with a cost-calculation sheet and a workbook for taking notes and making sketches. A facilitator mentor was allocated to each team to take observation notes and provide technical and logistic support. For our analysis, we followed the making activities of Team B. Audio and video recorders were used for capturing the making. The design artifacts consisting of sketches, written notes, and the final robot designed by the team were also collected.

3. Analysis

We adopted the case study methodology (Merriam, 2007) to unpack the processes involved in the making settings of Team B in the Maker activity-centered workshop. We combined constructionist perspectives with posthumanist standpoint to understand the ways in which makers and materials come together to configure the learning opportunities and creative movements (Keune, 2022). With constructionism pointing towards the ways in which learners realize ideas via design and embodied experiences to make meaningful expressions, and posthumanist consideration of material entities as active participants in phenomena, the dual theoretical approach augments our effort in following maker-material entanglements in learning and subsequent creative actions. We followed the dual theoretical perspectives and adopted the methodological process of thinking with theory (Jackson & Mazzei, 2012; St. Pierre, 2008). We viewed the assemblage of data sources simultaneously and iteratively. Here, we see ourselves entangled and becoming with the unfurling of research course. The research entanglement involved the encounter with data sources as video, photographs, design artifacts, field notes, and observations during making.

4. Findings

We found that makers and material entities of the situated making context came together and configured the entangled embodied enactments. We present representative episodes from the making context to show the embodied intra-actions enmeshing human and material entities where materials become actively engaged with learner bodies and provide the learners with opportunities for material ways of knowing.

B1 and B2 began design problem solving by rooting on the preliminary idea of a two wheeler robot with a cleaning unit attached so that the combination can drag the trash items along with it. The makers kept a close look at the cost component of the robot throughout the making process. The following episode illustrates how makers engaged with the materiality of the making context, where the embodied experiences lead to subsequent creative acts.

B1:	See [points to the robot].. we can move the robot forward and the sponge will push the paper bits out.
B2:	I will run it on the floor.
B2:	[Drives the two wheeler robot over the carpet] Its not good.. getting stuck at some place.. not smooth.
B1:	Lets try outside..
B2:	[changes the sponge orientation to horizontal]
B2:	[Drives the robot on the smoother test floor] better.. but it feels wiggly kind.

Figure 1. Team B makers driving the two wheeler robot with sponge attachment on different test floors.

Here the makers tried to make a two wheeler robot with a sponge that can push the trash materials as it travels forward. Once the sponge was fixed to the front end of the robot, B2 moved the robot over the carpet manually. The carpet resisted the robot motion as the sponge unit and carpet came into contact. B2 drove the robot manually and experienced the resistance through his body as the cleaning robot came in contact with the carpet. This encounter between the cleaning robot and the carpet pushed the makers to change the orientation of the sponge placement and the testing floor, as seen in Figure 1. The makers moved to a smoother floor to understand the motion of the cleaning robot unit. Again B2 drove the robot manually and felt the resistance in action. The makers perceived the notion of friction via embodied encounters where the different test floors, robot design, sponge and the maker bodies came together and arranged the spots for syntonicty. The particular instance from the making session is an example of how materials resist to maker actions and maker responds via embodied entanglements. Here we also read that the domain related concept of friction manifesting, and the makers acknowledging the same in the emergent learning opportunity. This opening helped them in understanding the notion of friction with varying surfaces in contact and how it affects the motion.

The makers proceeded with the session by considering changes in the robot design. From the previous tests, the makers ideated to use bigger wheels for the drive. As the next step, makers came up with the idea to eliminate sponge unit from the robot design and to have alternate cleaning mechanisms. In the following excerpt, we see that the makers make moves for a four wheeled robot, and the maker-material encounters provide insights to design stability.

B1:	Can we use bigger wheels or.. maybe four wheeled.. like a simple car with a broom.
B2:	We can.. [takes a lego motor and two wheels]
B1:	No sponge.
B2:	[Connects the lego motors and wheels to the brick with connectors]
B2:	[Exerts force on the robot from top] It's kind of weak.. moving up and down ..loose maybe.

Figure 2. B2 of Team B inspecting the robot design via embodied material ways

In the above episode, we can see that the makers looking for design possibilities and modifying design features. B2 examined the four wheeled robot for mobility, and checked whether the links are properly connected. As B2 tried to drive the robot on the glass table, he felt the robot clumsy. B2 then started to exert force on the robot from the top and followed by lifting the robot, as seen in Figure 2. The makers identified that the robot needs further reinforcements and design changes so that the intended purpose of cleaning is met. This unscripted play with the robot model gave the makers awareness of the stability of the robot. Here we see that the four wheeled robot, maker body, and knowledge from the previous experience are entangled in such a way that the collective embodiment of the making context paved way for the makers to be cognizant of the stability aspects of the robot design. The collective embodiment of the making context was not only shaped by the makers but also by its materiality and syntonicity.

Once the four wheeler robot structure was finalized, the makers turned their attention in making the cleaning unit. The makers envisioned having the cleaning unit to be attached to the rear end of the robot. As the idea of using sponge was eliminated, they looked for other possible material components for making the cleaning unit.

B1:	[Finds the cleaning wipe mop] this can be used.
B2:	I will check other things.
B1:	[Running fingers through the wipe mop] its soft..
B1:	[Finds the soft cardboard box and cuts out a piece]
B2:	Support?
B1:	[Attaches the cardboard piece with sponge using stapler pins] yeah.

B1:	[Cleans the paper trash with the cleaning unit] it works.. needs to be dragged with it.

Figure 3. B1 of Team B testing the cleaning wipe attachment by wiping the paper trash

B1 encountered a cleaning mop wipe on the working table and inspected it. B1 interviewed the cleaning mop wipe by visual inspection and running fingers through the wipe. The bodily engagement with the wipe revealed that it needed a support element so as to meet the purpose of cleaning and suitability of attachment to the robot structure. B1 cut a soft cardboard box, flattened the pieces, and used stapler pins to attach the soft cardboard piece with the cleaning mop wipe. B1 then tried to clean paper piece trash from the working table using the modified wipe manually, as seen in Figure 3. Here the meaning of cleaning is co-created by the maker body, the modified mop wipe, paper trash and the glass table, in conjunction. These materially syntonic intertwined bodily engagements and actions were crucial in identifying the necessary modes of wiping acts that the robot should perform. Although not explicitly, the test pointed towards the momentum and the material ways by which the robot is expected to produce the cleaning actions.

As the robot structure and cleaning unit were ready to use, makers used double tapes to connect both components. B2 proceeded with testing the cleaning robot by driving on the test floor manually and found that the mop wipe attachment was having contact with the robot wheels. The makers changed the orientation of the cleaning wipe mop, and B2 drove the cleaning robot over the paper trash, as seen in Figure 4. As B2 drove the robot, the makers found that the cleaning contact had good contact with the trash, but was unable to drag the trash with it due to the lack of momentum of the manual drive. The makers then followed up with changes in number of turns and speed of rotations for the Lego motors using programming. Here the cleaning robot and the maker body were in tandem during the test run which helped the maker to make sense of the wiping action of the combined maker-material effort with respect to the trash cleaned and momentum generated.

B2:	[Drives the robot on the floor] Feels like the mop is touching the robot wheels.
B1:	Make it little.. go up [gesturing in upward direction].
B2:	[Drives the robot on the floor] mm.. better.
B1:	Ok.. lets try with paper bits [spreads paper trash].
B2:	[Drives the robot on the floor] yeah.. its touching the pieces..
B1:	See.. but its not moving them.. going very slow
B2:	Yeah.. it’s the floor and paper
B1:	We can change the speed and motor turns [connects the robot to programing interface]

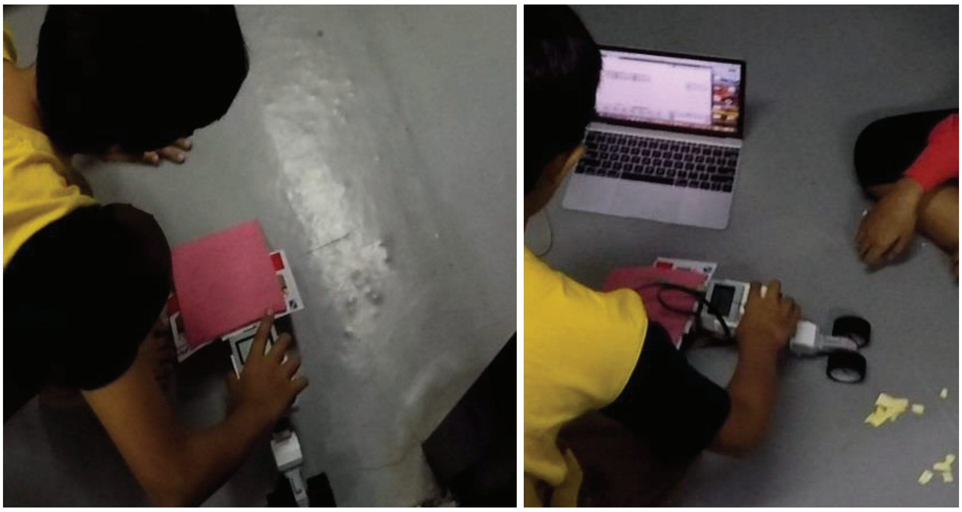

Figure 4. B2 driving the cleaning robot to follow robot motion and cleaning actions.

5. Discussion & Conclusion

In this article, we presented an empirical case study of collaborative making context from India where novice makers work on design problem solving with a variety of materials. We used a dual theoretical perspective of constructionism and posthumanism to examine the entangled embodied enactments when makers and materials come together and make together to shape learning opportunities. The constructionist approach helped us to see how makers enacted design ideas and domain related concepts via embodied ways, whereas the posthumanist lens revealed the active role of materiality in such entangled embodied experiences. With this standpoint, the study has put forward the need to reimagine the role of materials in embodied learning experiences. Here we advocate the point of departure from considering materials from mere mediators between learners and ideas, units for cognitive development *to* active co-participant in the relational field of encounters among learners and materials via bodily engagements. The active participation of materiality came into play as the material entities enmeshed with maker bodies in action, as in the case when the makers had to vary the test floor in accordance with the emergent meaning of resistance and motion. The intra-actions among the maker body, robot structure, sponge, test floors opened up opportunities for makers to get entangled with domain related concept of friction. In a similar way, the unexpected play modes of exerted and reactive forces among the maker body and robot structure brought out the ideas related to stability. The entanglements of the makers with cleaning mop, robot motion, paper trash, test floor, wiping moves, and programming directed the embodied experiences and material ways of knowing the momentum in action as the robot was driven manually to clear and carry the trash along the direction of motion. These instances highlighted how the emergent material syntonicity among materials and learner bodies provided the learners with opportunities for material ways of knowing.

Further, we found that that the creative acts featured in the maker workshop were not alone driven by makers. These creative movements were not only shaped by social entities but also by material entities of the making contexts. The findings signify that makers and materials molded the creative making that the processes span across the social and material elements of the situated environment, and flare out temporally (Sawyer & Dezutter, 2009; Tangaard, 2013). We noticed that maker-material and maker-maker encounters through dialogues and embodied experiences helped in knowledge co-construction that helped to investigate possible solution approaches for the design problem. With this article, we attempt to place the combined theoretical perspectives of constructionism and posthumanism as a way to look at embodied entanglements in collaborative making, following the concept of material syntonicity. We place collaborative making as a potential research domain to implement and advance the understanding of maker-material entangled embodied experiences and relations to enhance learning, where the creative phenomena evolve in a flat plane of contributing entities (Petrich et. al., 2013; Thiel, 2015; Timotheou & Ioannou, 2019).

The present study focused on data associated with a typical collaborative making context in which makers engage in solving design problems through making, however, advanced studies are required to understand and mark further modes of maker-material entanglements in collaborative creative making.

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