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Actions and Interactions at Collaborative Engineering Design Hackathon: Looking Through the Lens of Embodied Cognition

Soumya NARAYANAN[a*], Navneet KAUR[b] & Rwitajit MAJUMDAR[c]
[a]*KLE Technological University, India*
[b]*UNESCO MGIEP, India*
[c]*Kumamoto University, Japan*
*n.soumya@kletech.ac.in

Abstract: Engineering design is an important aspect of engineering education. The essence of engineering design process has been conveyed to students in diverse ways such as formal capstone and cornerstone projects or informal processes such as hackathons. The interdisciplinary nature of engineering design projects often prove challenging to students in multiple ways. As informal opportunities, hackathons have the potential to acquaint students with several skills key to interdisciplinary engineering design. This paper investigates the contribution of one such hackathon – a medical device innovation hackathon, in supporting student understanding and learning of engineering design process. Specifically, the paper examines the influence embodied cognition plays on supporting student understanding of an engineering design problem that cuts across multiple disciplines. In the case study, we describe an episode where a team of students go through the gradual process of comprehending the design problem along with the accompanying design complexities through descriptive narration, and simulation.

Keywords: Learning by doing, embodied cognition, grounding in the interactions with physical world

1. Introduction

Engineering design is an important aspect of engineering practice and ability to design is a key skill expected from graduating engineering students. To nurture this skill, students are exposed to a variety of projects in the course of their engineering education. This includes formal academic project experiences in the form of capstone, cornerstone projects and international design challenges such as solar decathlon, NASA Human Exploration Rover Challenge (HERC), and ASME Student Design Competition covering extracurricular engineering design activities. While capstone and cornerstone design experiences make an effort to support students in developing their cognitive, metacognitive, and interpersonal skills integral to design projects, they carry significant academic weight with academic repercussions to the students thereby acting as a deterrent to creative exploration (Rennick et al., 2023). The international design challenges typically have a larger scale with dedicated sub-teams competing at an international level. They are also often spread over a longer time duration. At a smaller scale, tinkering in makerspaces (Peppler, 2022) have emerged as a popular informal interest-driven platform for engaging in creative experimentation. Somewhere between the large scale projects and small scale tinkering are the Hackathons (Rennick et al., 2023; Flus et al., 2021). Hackathons are stringently time constrained, uninterrupted immersive events, where participants gather in teams and solve design challenges (Rennick et al., 2023; Flus et al., 2021). Further, hackathons are low-stakes events where participants work on open-ended problems without academic implications but gaining rich experience and exposure to engineering design process. Hackathons are typically theme specific and competitive and can have diverse purposes such as education, innovation, social awareness on healthcare, sustainability and so on.

During Hackathon events, participants engage with an open-ended interdisciplinary engineering design problem. Such design problems are ill-structured, with no clearly specified goals, requirements, constraints and innumerable ways to solve them. There are several cognitive processes (Hay et al., 2017) that come into play when a collaborating design team tackle a design problem. Some of these include problem structuring, critical thinking, retrieval, reasoning, generation, transformation and synthesis of concepts, concept evaluation, decision making and so on. One of the key parts of engineering design is problem understanding (Dym et al., 2005). Considering the theme of hackathons could cover a diverse range of disciplines typical of engineering design problems, design exploration towards problem understanding assumes primary importance. With avenues for tinkering and frugal prototyping in most hackathons, the aspect of doing opens up vast potentials for problem understanding. Specifically, the actions of the body and interactions with tools and systems during the doing process of design, influences the design cognition. This paper is a case study of one such hackathon experience where the design problem understanding via bodily actions are examined with the lens of embodied cognition.

2. Background

All Understanding the problem is a critical component of the design process because it shapes the direction and outcome of subsequent design activities. In this phase, designers define and structure the problem space by identifying core issues and constraints, which is crucial for clarifying design constraints and objectives (Dym et al., 2005). Interdisciplinary teams are essential in design problem-solving, especially when it comes to enhancing problem understanding. Bucciarelli (2002) emphasizes that team members in interdisciplinary teams engage with both technical and social dimensions, facilitating a more comprehensive understanding of the problem. In this context, verbal communication and material interactions among team members help frame the design problem, contributing to a clearer definition of the problem.

Schön (1983) suggests that design can be viewed as a "conversation with the situation," where hands-on engagement with materials uncovers opportunities and constraints that abstract thinking alone cannot reveal. For instance, in the design of medical tools or complex engineering systems, physical prototypes allow designers to explore usability, ergonomics, and functionality (Deininger, Daly, Sienko, & Lee, 2017). Similarly, manipulating physical prototypes provides direct, tangible feedback that guides iterative refinement and problem-solving (Lim, Stolterman, & Tenenberg, 2008). Therefore, problem understanding is shaped by various methods, including peer discussions, consultations with experts, and physical interactions with tools or materials. These methods engage different cognitive processes, allowing for a deeper understanding of the problem.

Spatial cognition, which involves key cognitive processes involved in design tasks like mental manipulation and rotation, spatial perception and spatial visualisation and (Sutton & Williams, 2007), is significantly influenced by embodied interactions. Research shows that bodily and action states impact spatial abilities. For instance, mental rotation tasks are enhanced by congruent motor actions, suggesting that spatial skills are scaffolded by the motor system (Athreya, Chandrasekharan, & Srinivasan, 2006). Studies on perspective-taking and navigation also indicate that spatial cognition is shaped by the body's interaction with the environment (Hegarty & Waller, 2004; (Darken & Peterson, 2002). These findings illustrate how the physical state of the body influences both spatial perception and application of spatial skills. In the context of design, these may have implications, for example when individuals engage in critical discussions, their embodied interactions—such as gesturing, drawing diagrams, or physically manipulating objects—can enhance how teams visualize and conceptualize spatial relationships. Similarly, the tactile experience of working with different materials—such as feeling the weight of a prototype or observing how materials behave under different conditions—can significantly impact spatial cognition and understanding of the design problem. In a study involving industrial engineering students, a workshop with robot manipulators demonstrated how embodied interactions improve spatial awareness and problem-solving skills (Verner, Cuperman, Gamer, & Polishuk, 2020). Students operated both conventional and modern robots in virtual and physical modes, showing that hands-on experience with robots enriched their spatial understanding highlighting the role of embodied experiences in deepening problem understanding.

Although we have gained some insights into the role of embodied cognition in design, further research is needed to explore how different levels of embodiment, such as using low-fidelity versus high-fidelity prototypes, impact problem understanding or how interaction such as physical manipulation, verbal communication, and material engagement affect the refinement and articulation of design problems, particularly within interdisciplinary teams. A deeper investigation is essential to understand how these dynamics interact and in what specific ways they contribute to a more cohesive and effective problem-framing process and ultimately how teams with varied expertise and backgrounds collaborate to solve complex, design problems.

3. Theoretical basis

3.1 Embodied cognition

Embodied cognition is a concept that emphasizes the role of bodily actions, experiences and interactions with the environment, in shaping the cognitive processes (Rahaman et al., 2018). The two theories of embodied cognition that can provide a mechanistic explanation to the design problem understanding process are tool or manipulative incorporation (Sinha et al., 2021; Maravita and Iriki, 2004) and common coding (Sinha et al., 2021; Rahaman et al., 2018).

3.2 Tool / manipulative incorporation

Tool use has been known to extend the body schema to incorporate external objects. In an experiment on monkeys, Maravita and Iriki (2004) demonstrated that when users incorporate the tool, it extends their imagination by opening up a range of new possibilities of action and correspondingly impact imagination. The expanded range also extends the understanding or knowledge of the tool and the space around it (Sinha et al., 2021; Rahaman et al., 2018). Tools or manipulative have also been known to aid in cognition by acting as providing multiple perspectives to a concept by working as an instance of multiple representation. Physical manipulative also aid in distributing working memory load to the external environment (Sinha et al., 2021; Rahaman et al., 2018). Finally, manipulative have been known to aid in strategy change and consequent shift in cognitive processes. Actions require integration of motor and sensory elements. This integration is activated by manipulation tasks that in turn prompts shift in cognitive processes and strategies.

3.3 Common coding

According to common coding theory, perception, execution and imagination of movements have a common representation such that any of the 3 entities when activated, trigger the others. So if one perceives and imagines specific actions, his or her motor system is implicitly activated. Conversely, executing movements or actions can lead to improved perception and imagination (Sinha et al., 2021; Rahaman et al., 2018). Common coding connects execution and imagination by what is known as action priming. Here, traces of the actions done on the manipulative are stored and activated in imagination during problem-solving. Types of bodily actions that an individual can perform, influences the perception of the external environment and in-turn cognition. Thus perception and cognition are tightly linked and shaped by bodily actions. Further, spatial cognition is also shaped by bodily actions. In the context of hackathons, the role of embodied cognition can be understood by the actions possible in the problem solving process and also the extension of imagination that manipulable or tools offer.

4. Research method

4.1 Research question

In this paper, we are interested in investigating, 'how can embodied cognition influence the understanding of design problem?' To answer this question, we examine an episode involving problem understanding in a medical innovation hackathon.

4.2 Analysis method

We use the method of case study to examine a specific episode involving design problem understanding in a team. This method is appropriate in our context because case studies enable readers to understand unique situations in real scenarios clearly using rich and vivid description of events relevant to the event (Cohen et al., 2002). Case study is a powerful method to observe effects in real context, recognize the underlying determinants of the causes and effects. Also case studies help investigate complex dynamics and interactions along with individual actions by portraying participants' experiences in the real context.

5. Case Study

5.1 Context

The context is a medical-engineering design hackathon organized by BETiC - a medical device innovation center. This case study describes the design process of one team who participated in the hackathon held during the year 2018. The hackathon lasted for 3 days during which teams of students were mentored on key engineering design processes and strategies while simultaneously working towards coming up with conceptual designs for the given problem. The students are mainly from undergraduate engineering disciplines with four members from diverse backgrounds forming a team. Among the four team members, one of them is a doctor who takes up the role of a client and constantly interacts with the students to convey the need. At the end of 3 days, students are expected to present conceptual designs for the given problem statement with a demonstrable prototype if possible. The team explored both the problem space incorporating the problem requirements and the solution space encompassing possible design solutions and means of evaluating the requirements, iteratively leading to parallel evolution of design problems and solutions.

5.2 The problem statement

The design requirement was for a technology solution to help laparoscopic surgeons in their suturing activity. The suturing needle used in laparoscopic surgery is curved. Suturing requires the suturing needle to enter the tissue at right angle. However due to the limited viewing angle offered by the camera within the laparoscopic surgery location, it is difficult to ensure needle entry at right angle to the tissue. The problem statement requires the students to devise a technology solution to address this problem. The design process followed by the team was predominantly co-evolution of problem and solution space.

5.3 Understanding the problem

Initially, the team came up with a broad problem statement viz. The development of an instrument for laparoscopic surgeons to perform precise and efficient suturing. The premise was that laparoscopic suturing is difficult, requires expertise and intense prolonged practice, and can cause complications if performed wrongly. The initial problem specified three steps:

- Grasping the tissues.

- Piercing using curved needle involving sub-steps of holding needle at right angle and piercing the tissue at right angle.
- Tying the knot at the end of suturing.

Among these, the clinical need was for holding needle at right angle and piercing the tissue at right angle. The need for such a system was justified considering reduced learning curve leading to increase in number of surgeons who could suture precisely without undue complications, functional limitations of existing suturing devices, differences in texture (hard and soft) of different tissues leading to complications in suturing and improved ergonomics leading to reduction in surgeons occupational health issues such as shoulder pain.

The problem of laparoscopic suturing, is difficult to empathize with as the issue is evident and relevant to only a small section of medical professionals who practice laparoscopic surgery. Laparoscopic surgeons extensively train to coordinate their hand movements based on the indirect feedback from a camera inserted along with the laparoscopic needle driving tool, on a screen. The difficulty of not directly viewing the operating area is compounded with the fact that the maneuverable area is extremely limited. Additionally, the laparoscopic needle used for suturing is curved as they facilitate suturing in spaces that have less scope for maneuvering. With these severe constraints of directing one's actions based on indirect visual feedback and limited maneuverable area, the ability to suture precisely becomes a challenging task. For engineers, understanding this problem is not straightforward.

The doctor in the team consequently, found it challenging to convey the difficulty of suturing tasks to the undergraduate engineering students. The team spent a large proportion of their hackathon time in understanding the problem clearly. Towards this, the doctor came up with several strategies to tackle this challenge.

5.4 Introducing Laparoscopic instruments to the team

The doctor brought with her a partial set of genuine laparoscopic instruments for the students to see, handle and manipulate. Students got familiar with the different functionalities of the instruments, understood the need for a curved needle, why straight needles cannot be utilized and the correct way of holding the needle at right angle to the instrument, as can be seen from the sequence of sub-images in figure 1. This was valuable input for the students as students experienced the challenges involved in holding the curved needle and wielding the instruments correctly.

Figure 1: Students getting familiar with laparoscopic instruments

5.5 Using props to convey the problem

Though the availability of real instruments was a strong contributor to understanding the scenario of laparoscopic surgery, the need for and the difficulty of right angle entry of instrument with respect to tissue was difficult to convey. The doctor used paper cups, apple fruit and so on to explain the problem. The two sub-images in figure 2 depict the simulation of the suturing process assuming the paper cups as the tissue sections to be sutured. Meanwhile the students tried to simulate the suturing process by trying to poke through the paper cups and apple using the laparoscopic instrument and needle, at right angle as required for correct suturing.

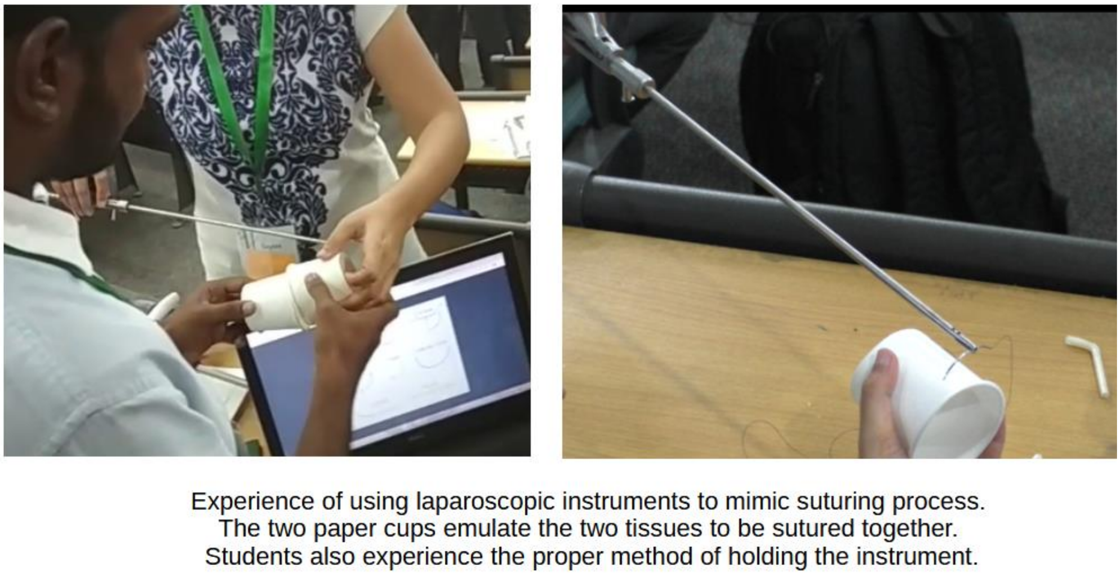

Figure 2: Simulating suturing process using laparoscopic instruments and props

5.6 Simulating the whole process

While the props helped the students understand the intricacies involved with the problem of needle entry at right angle, it could not convey the constraint of limited space and indirect visual feedback. In order to understand this aspect thoroughly, the students along with the doctor tried to simulate this entire scenario. For this the team employed a cardboard box with a hole substituting for the human body being operated on. A smart phone positioned inside the box video communicated with a smartphone positioned outside through video call, providing the visuals of the internals of the closed cardboard box. A third smartphone placed inside the box provided illumination. Students tried to maneuver the laparoscopic instruments via the hole in the box while viewing the video feed on the external smartphone communicated by the internal smartphone. This exercise involving actual tool manipulation within the confines of the hole or incision in the box, as seen in the sub-images of figure 3, provided the students with the most clearest understanding of the challenge of suturing in the constrained conditions.

5.7 Problem and solution co-evolution

Initial solution brainstormed with preliminary understanding of the problem included use of glue like material instead of suturing, use of band-aid like method instead of suturing, use of coagulants to join two tissues, and use of zip like arrangement to connect two different tissues together. However, following the increased understanding of the problem, the accompanying imagination of potential solutions expanded, taking into account the different restrictions and limitations of the suturing scenario. The sub-images in figure 4 depict the attempts to ideate potential solutions. Students proposed different solution ideas to the doctor and tried to demonstrate the solution idea using the same artifacts. One of the potential solutions proposed was the use of two lasers that can form a cross-hair like image on the tissue, thereby indicating the point of entry.

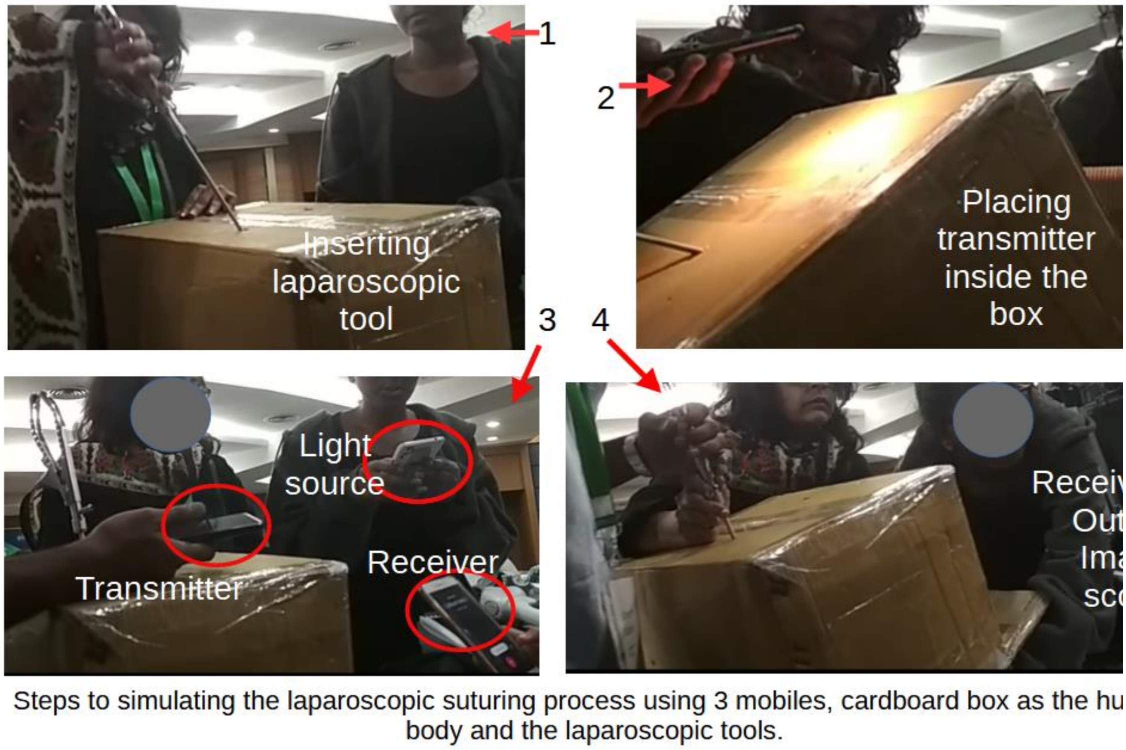

Figure 3: Simulating to understand the spatial constraints of the problem

Figure 4: Extending imagination to explore potential solutions

6. Discussion

In the episode analyzed from the hackathon, we examined how embodied cognition can influence the understanding of design problem? To answer this, we begin with tool incorporation (Sinha et al., 2021; Rahaman et al., 2018). To acquaint the students with the different actions and affordances of the laparoscopic instruments, the doctor in the team procured and introduced the undergraduate engineers to actual laparoscopic instruments. The students could explore handling the instruments and the various affordances of the instrument. To gradually deepen the familiarity, the doctor followed this with simulation of suturing process using different props. In this scenario, the participants experienced an extension of their body schema by trying to mimic the suturing process on different props such as paper cups and fruits. This simulation contributed to the students' understanding of the requirement of relative position of needle and the laparoscopic instrument. Additionally, students were able to understand the challenge of manipulating the needle to pierce the two tissues to be sutured at right angles. Here the action of holding the needle and piercing the props using the needle enabled the perception and cognition.

In the final scenario, the perception of spatial limitations and restrictions imposed by the inherent nature of laparoscopic surgery via simulations of the environment, accompanied with possible actions, contributed to the spatial cognition or in this context the understanding of the problem of suturing in a limited space using indirect visual feedback. Embodied cognition thus enabled students to extend their imagination by incorporating the tool or manipulable into their body schema and perform actions. Additionally, embodied cognition influenced the students appreciation of the spatial constraints in the actual problem environment by the common coding of action-perception-imagination. The role of tool incorporation and common coding to support makerspace practices is also emphasized by Sinha et al., (2021). They proposed thinking with tools and prototypes to support a chain of imagination and generation.

7. Conclusion

The case study described in this paper brings out the importance of 'doing' in the context of design problem understanding leading to appropriate problem definition. This emphasizes the importance of techniques like frugal prototyping and playful tinkering during design problem solving to not just come up with solutions but also to understand the problem more comprehensively, empathize with the requirement and extend imagination to creative solutions.

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