2018 IEEE 18th International Conference on Advanced Learning Technologies

"Help me Build": Making as an Enabler for Problem Solving in Engineering Design

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***Abstract*—Solving engineering design problems requires the students to explore and understand the solution space to think creatively. Most of the current teaching practices of problem-solving in the context of engineering design are very structured not allowing much room for exploration. Making is the act of building or adaptation of objects to understand the functions of our environment. It involves opportunities to order the immediate environment around oneself which can serve as a cognitive function to provide insight into multiple solution strategies. In this doctoral research, we propose to build a learning environment (LE) to support the learners in learning the key skills and processes essential for making. With the help of some maker-studies, we will try to identify the key skills and strategies that they apply while making. In studies with novice makers, we will try to determine the challenges faced in learning and application of such skills. The findings from these studies will guide the design of our LE to support the learning of making.**

***Index Terms*—Makers, Problem-solving, Engineering-Design, Makerspcae**

1. Introduction

Making is to build or adapt objects by hand, for the simple personal pleasure of figuring out how things work [1]. The use of the hands is essential as they enhance our cognitive capacities by allowing us to perform actions in forms of sensory motor activities which helps us experience the world around us. The actions that are performed with the hands allows us to understand the objects to adapt them to our use. The want for such an adaptation could be driven by the need to understand our environment, to perform some essential functions or to play with it [2]. Learning technologies have been designed to encourage and support such processes of making [3].

Engineering design (ED) as defined by ABET is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), where decisions are made based on the knowledge and optimal use of resources to meet a stated objective. Development of student creativity, consideration of alternative solutions, the inclusion of a variety of realistic constraints are among the essential features to be taken care of when teaching ED. The emphasis is on teaching ED via problem-solving in the form of projects [4]. The exposure to problem-solving especially in the laboratories of first-year engineering students is very systematic and by the book which does not encourage exploration, curiosity building, and the need for investigation and discovery [5]. This lack of exposure hinders the growth a making attitude which hampers opportunities for creative and innovative thinking.

In contrast with the traditional educational practices, making follows the constructionist theories [6]. It is learner driven and supports inquiry-based and discovery-based learning pedagogues. Making allows makers situate their mental models by building with the available resources in the physical space enabling them to manipulate their construction in the physical space and test their mental models [2]. They start with some ideas in mind, and as they build, they keep modifying the plan based on what they experience in the process of making. A maker continuously keeps evaluating the solution approach based on the known and emergent constraints during the building process. This process enables the maker to reflect on their decisions at every stage of construction, allowing them to take multiple solutions approach.

For innovative solutions, it is essential for the learners to be able to understand the environment based on the affordances it offers and constraints it imposes. This understanding helps in exploring the problem space and available resources for a solution [7]. Being situated in the context of the problem enables a better understanding of the resources and constraints while building solutions for such complex problems. Making focuses on the creation of a solution in the form of an artifact that is situated in the context of the problem and hence the maker has to work with the constrained resources from the beginning. They address such constraints by applying heuristics for repurposing known solutions or creating innovative solutions.

Making has been adopted as a pedagogy by several STEM, electronics, and computer science education researchers [8]. These studies have reported an increase in engagement, collaboration and other affective parameters due to making. A few research works have [9] [10] reported

2161-377X/18/$31.00 ©2018 IEEE
DOI 10.1109/ICALT.2018.00113

on thinking skills and competencies that have been observed among participants during their making assignments. However, not many studies have tried to look at the process of making through the lens of the skills and processes of making that are essential to the making process [8]. There has been less work which focuses on the building of pedagogical environments for learning of making though technologies that support making are widely available. Availability of making technologies motivates us to explore in depth the essential processes and skills of making and further explore how pedagogies can be designed to enable the learning of these processes. Making has been widely used in innovative approaches to solving complex problems like frugal innovations, grassroots innovations, bricolage, and disruptive innovation. Here makers choose to constrain their solution space by making with what is available which makes application of heuristics easier [7].

This paper discusses the studies we plan to conduct to identify the skills and processes used by makers to help to understand the solution space and build in it. Finding from these studies will inform the design of the learning environment.

2. Proposed Solution

The skills and processes used by experienced makers allow them to understand the problem environment and solution space well. To teach these skills and processes of making we propose to build a learning environment where we choose to constrain the solution space with a robotics kit to ensure makers focus on exploration functions and affordances of the available components instead of hunting for the ideal components.

We will be using the Lego Mindstorm [11] as the construction kit which will allow them to think of the sensors and actuators in an abstract form of their function. This aspect of the kit will enable them to add and remove them depending on the functionality they want to achieve. Moreover, it has been extensively used by researchers and practitioners for maker based pedagogies [9].

Our focus will be on building the skills and processes using which the makers explore the components of the kit to understand its capabilities and constraints better so they can apply these skills and processes to build a solution. Further, we will try to find out the impact of this understanding of the kit on the problem they try to solve.

3. Research Study

We plan to conduct studies with novice and experienced makers. Novice makers are those who are interested but have not practiced making in the domain of engineering design, and experienced makers are who have been extensively making as a hobby or profession in the domain of engineering design.

From the initial studies, we aim to understand various processes and strategies for making by observing the experienced makers make things as they solve problems that align with their interests. We also aim to uncover challenges and inhibitions of novice makers by introducing them to a robotics kit and observing them as they explore it. Then we let them build objects and solve problems aligned to their interests, e.g., for a maker who has a pet fish and is interested in home automation the problem could be I plan to go out for the weekend but cant carry my goldfish with me. All I have is a Lego Mindstorm kit. Help me build something that will feed my fish on time.

A participant who has interest in making but has not been making will be considered for the novice studies and participants with experience in the making in the domain of engineering design will be considered for the expert studies. The target audience for the study is Indian students who have graduated from high school or ones who have just entered engineering. At that stage, the focus of STEM education is highly instructional, but that is the stage when one is building some most basic and essential concepts of STEM that are essential for engineering problem solving and solution design.

3.1. Procedure

The study is divided into three stages. In the first stage, the maker will be given a construction model with an instruction sheet to help them build the model step by step. The objective of this stage is for the learner to explore the components of the construction kit and the programming environment. This stage will also help us understand how makers approach a new set of building material. Further, it will also help us differentiate between approaches and behaviors of a novice from a regular maker.

In the second stage of the study, the maker will be asked to build a simple generic model. We will try to align the construction models with the interests of the participants, e.g., build a bot that looks like an animal. The objective of this phase will be to see how the makers use their experiences from the first phase into the second phase. Moreover, do the learners consider factors beyond what the objective asks them to build, e.g., trying to include the behavior of an animal along with the looks of it when making the robot.

In the third and final stage, the maker will be given a problem from the domain of engineering design an example of which has been discussed in the previous section. Makers have to construct a model as a solution to the problem. The problems will be open-ended to which the researchers have already created solutions using the construction kit. The makers will be allowed internet access. They will not be restricted from building models that are available online, but this will not be explicitly mentioned. The objective of this stage is to identify how has the experience of exploration aided in solving the problem using make.

3.2. Data Collection and Analysis

During all the three stages the researcher will not contribute to the exploration and the building process but will interact with the maker to get insights into their process of making. One of the ways to achieve this would be to use stimulated recall to talk about the moments when the maker has shown signs of success or failure after the session. The researcher would also interact with the maker as they test an approach taken like constructing a sub-component. We will ensure that the interaction doesnt interfere with the chain of thought of the maker.

The entire session will be videotaped, and the audio of the interactions and interviews will be recorded. The interaction with the programming software will be captured in a screen recording. These recordings from all the three phases will then be analyzed using broad themes like actions and behaviors representative of processes and skills observed during the exploration of the kit to identify its capabilities and constraints. Narratives of video snippets that seem vital towards the themes will be created and further coded. These codes will be analyzed for patterns in spatial and temporal domains. The observations in the spatial domains will help us identify key skills based on their frequency or occurrence. Observations in the temporal domain will help us understand the processes that have been observed. These will help us to determine the skill and the processes essential for learning of making. A comparison between the coded narrative of novice vs. the experienced makers will help us understand the challenges faced by the novice and determine the zone of proximal development to help us in designing scaffolds for the novice.

4. Research Questions

The Main Research questions for the initial study are:-

1) **What key skills and strategies are used by experienced makers that are essential for making?**
A few follow up questions would be What enables them to perform a self-initiated exploration to build an understanding of the working environment? The objective would be to look for the thought process that enables a maker to decide the various aspects of inquiry while carrying out these explorations. This question will be answered from the phase one and two of the studies done with experienced makers.

2) **What are the challenges faced by novice makers in learning the essential practices of making?**
Our focus would be to look for shortcomings of a novice to be able to explore the environment and then integrate these experiences to use the capacities of the environment in solving the problem. This question will be answered from the phase one and two of the studies done with novice makers.

3) **What other factors than the components in the environment enable the makers to build a solution based on their experiences with the environment?**

5. Conclusion

With this research, we attempt to understand the making skills and processes. The finding from these studies will guide us in creating a learning environment and design a pedagogy for learning of making. The objective of this DC proposal to the get feedback on the study design and inputs on the approach towards creation of such a learning environment for making.

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