Rodrigo, M. M. T. et al. (Eds.) (2021). Proceedings of the 29th International Conference on Computers in Education. Asia-Pacific Society for Computers in Education

Tinkery: A Tinkerer's Nursery for Problem Solving with Lego Mindstorms

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Abstract: Problem-solving, in most of the engineering design laboratories is still systematic by the book, lacking exploration, curiosity building, investigation and discovery. Even with the wide availability of tinkering kits designed in accordance with tinkerablilty, their ability to nurture tinkering is limited to few pre-built models and instruction manuals. In this paper we discuss building experiences of exploration and play as an operational understanding of tinkering. Guided by our understanding and tinkering practices we designed Tink-table a learning environment to nurture tinkering by solving engineering design problems in the domain of robotics. Tink-table uses a Lego Mindstorm kit, is supported by our XprSEv (read as expressive) pedagogy, has a set of problems and a mentor. This paper presents the design of Tink-table along with a study design to understand its role in nurturing tinkering. We present observations of a preliminary study that align with our understanding of tinkering.

Keywords: Tinkering, problem solving, lego mindstorms, robotics, learning environment

1. Introduction

The tinkering movement has gained tremendous momentum and one of its significant indicators in India was the establishment of Atal Tinker labs by The NITI Aayog Govt. Of India under the Atal innovation mission (AIM) of 2016. Under AIM 7200+ schools have Atal Tike labs established. Tinkering provides learners with a playful curious inductive perspective to problem and solution along with the deductive approach. Tinkering, not limited to engineering design, enables a learner with the skill of approaching the unknown and being able to explore and gain with the experience (Dym et al., 2005). The current generation has been provided with a variety and access to a lot of inclusive tinkerable tools and materials, some of which have been designed based on research to ensure tinerability and support tinkering ability. Based on our experience of using such kits we realize the support for nurturing tinkering abilities is limited to the pre-built models and instruction manuals which limits their potential as tools for the joy and love of tinkering and learning (Mitchel Resnick, 2017). The other challenge is that the formal setting for problem-solving, especially in the laboratories of engineering design, is very systematic and by the book, which does not encourage exploration, curiosity building, and the need for investigation and discovery (Atman & Bursic, 1996).

The broad objective of our research is to design a pedagogical strategy with a learning environment to nurture an attitude of tinkering for solving engineering design problems as an alternate approach to problem-solving. Also, to facilitate mentors in nurturing a tinkering attitude among problem solvers and learners. In order to reach the goals, we attempt to identify operational nuances of tinkering and use them to develop a learning solution for nurturing tinkering. In this paper we discuss our operational understanding of tinkering use it to design our learning environment called Tink-table and its components which are the XpeSEv pedagogy, building resources, problem statements and the mentor. We also present our observations from a single participant preliminary study.

2. Literature

Tinkering has been expressed in forms of various characteristics (Resnick & Rosenbaum, 2013; Stager & Martinez, 2013), narratives (Dougherthy, Honey, & Kanter, 2013) and as ways of life (Louridas, 1999). Tinkering has been considered as a novice and expert practice which sets it apart from most of the classroom practices (Danielak et al., 2014). It does not make tinkering better or worse but it does make it an authentic professional practice (Berland et al. , 2013). Tinkering is also associated with "jugaad" and "bricolage". From bricolage comes an attitude of building experiences from the immediate sensory perceptions by exploration and experimentation (Louridas, 1999) and from jugaad the ideas of starting with a quick fix (Radjou et al., 2012). In contrast, deliberate sensemaking aims at conceptual understanding but in tinkering producing an outcome is a primary goal. It could drive deliberate sensemaking, only in service of the outcome (Quan & Gupta, 2020).

Research in engineering design has recognized that iteration and experimentation supports generation of knowledge and designs refinements (Dym et al., 2005). With rapid prototyping, the generation of manipulable artifacts from the initial design ideas to refine the design (Berland et al., 2013), overlaps with tinkering as it is improvisational and iterative toward the design goals (Baker et al., 2008). In design, the goal is to produce an artifact or solution while the terms of success are not well-defined and multiple solutions approaches are possible. The engineering design process also uses multiple approaches (Dym et al., 2005), while solving a complex problem (Jonassen, 2000), tinkering is one such practice of the engineering design process. Tinkering, like all engineering activities, is a situated phenomenon (Johri et al., 2011). Tinkering emerges within interactions between students and their in-the-moment goals and is sustained by feedback from the social and material environment. Tinkering as per our understanding, is a disposition based on inquiry into the problem and solution space further mapping it to one's associated knowledge while solving it. Tinkering is an iterative experience-driven approach which is full of short and long cycles of quick experimentation which results in observations leading to a different or new understanding. Through these short and long cycles emerges an improved understanding with which the solution continues the evolution.

3. When We Tinker

Many discussions associate tinkering with playful explorations at its core (Mitchel Resnick, 2017). Two distinct interactions, emerge as important; *exploration* - which is asking the question "*what things do?*" and *play* which is "*what can I do with them?*" (Zubrowski, n.d.). These activities allow learners to build repositories of experiences. An experience is an interaction and/or an investigation that gives rise to observations developing some understanding. The learners later draw from these experiences when faced with challenges (Dyasi, n.d.). This aligns to classic bricolage literature where (Louridas, 1999) for a tinkerer there is a repository of experience-based understanding that comes from asking the questions "*what can something do*?" (Exploration) and "*what do I want to do with it*?" (Play). So, problem solving for a tinkerer is having interactions with problem and solution space which consist of a lot of explore and play to build some understanding about them. Then start with a quick fix and continue to evolve as understanding develops. Hence, Our understanding of a tinkerers way to problem solving is1) Exploration of resources (solution space) with the question "*What can the resources do?*" and problems (problem space) with the question "*What do I want to do for the problem?*" and 2) Play with the understanding of what things "*can do*" and the things I "*want to do*" to create a mapping between them by answering the question "*What should the resource do for me?*". The answers either lead to modification of ones understanding of the resources or the way they perceive the problem. Through the evolution of these understanding of the resources and the problem the solution evolves. With this as an operational understanding as our theoretical framework we strive to nurturing an attitude of exploration and play, or for someone who already does it, make it explicit.

4. Nurturing Tinkering

Based on the operational understanding of tinkering, literature and a few pervious explorations (Raina et al., 2018, 2019) we have designed Tink-table our learning environment. Tink-Table is built on four aspects namely The XprSEv (read as expressive) pedagogy, A set of problems from the domain of robotics, building resources which in our case is Lego Mindstorms, and a mentor.

4.1 *The XpreSEv Pedagogy*

The pedagogue is based on our previous explorations with tinkering and derives from the models of tinkering (Mitchel Resnick, 2017). The elements pertaining to Tinkerability and supporting tinkering ability have also been considered (Mitchel Resnick, 2017). The pedagogy is primarily based on three objectives namely explore, solve and evolve. With explore, the learners focus on learning to explore the problem and solution space. In Tink-table this objective is operationalised into phase 1 where learners start with small challenges situated in context robotics, which requires them to interact with the physical space using the components of the robotics kits to understand their affordances to solve these challenges. With solve, the learners focus on play by mapping their understanding of the resources to what they would want to do to solve the problem. In Tink-table this objective is operationalised in phase 2 in addition to previous objectives where the learners use their understanding of the robotics kit and try to map it to a way, they would want to approach the given problem. If a mapping is not achieved the learner either updates their understanding of the use of the resources from the robotics kit or works on a different way to solve the problem based on what resources are available. With evolve, the learners focus on evolving their solution in terms of structure or function. In Tink-table it is operationalized in phase 3 along with phase 1 and 2 where the learners are asked to frame a new problem in robotics or think of a way of solving an emergent problem in the solution of the previous given problem.

The challenges given in phases 1 are candidate sub problems for the problem given in phase two and three. This is done adhering to on progressive formalization. The Objectives determine the focus of problems designed for each phase and the activities to be performed by the mentor. A summary of the same has been present in Table 1.

Table 1. *Operationalization of the XprSEv Pedagogy into Three Phases.*

Phases	Objectives	Activity Focus	Learner Goals
1	Explore	Explore resource affordance and use them to solve candidate problems	Understand and use resources as per affordances and find the affordances required for their solution approach.
2	Solve	Solve problem by finding solutions for sub problems with the given resources.	Divide into subproblems & identify affordances. Use resources based affordances OR solve sub problems as per affordances of the resources available.
3	Evolve	Improve solution or solve emergent challenges by refining sub problems while reflecting on interaction.	Improve the solution by exploring alternate resources for sub problems and playing with their affordances.

4.2 *The Problems*

The problems are designed to progressively complicate yet allow the learners to connect their understanding from one to the other allowing progressive formalisation with the resources and the materials available. The problems are based on the Lego kit. Learners are initially given challenges that nudges them to explore the affordances of the components available in the kit. The challenges require them to use a particular affordance of the resource offered in the kit in a way they are able to explore the possibilities of what the resources can do. The next problem is based on the challenges given initially. Finally, the learners try to refine the solution of the problem or attempt a problem is of their choosing.

4.3 *The Mentor*

The role of the mentor is of a non-contributing participant. The mentor has to be very well versed with the entire problems by solving them and exploring variations. It helps mentors to empathizes with the learners and scaffold them towards exploration and play in terms of can do's and want to do's by posing questions. The mentor's approach is shared by talking about how and why they thought or suggested certain possibilities. It is recommended to give multiple possible approaches and leave the decision of trajectory to learner. The mentors could intervene if they encounter learners in discomfort and scaffold them towards flow. The mentor foresee a lot of challenges in the learner's trajectory, but not interrupt the learner unless learners ask for help. If the mentor does foresee failure, should allow the learner to observe failure but question later. It is a crucial step to develop an understanding about the resources and the solution approach. One preferred approach is to re-articulate the questions posed by the learners which brings clarity that the learner and the mentor are on the same page and also acts as a trigger for reflection for the learner. Mentor can bring the learner to a point where lot of possibilities exist without explicitly mentioning them. Then get the learner to think about possibilities or give suggestions by using the resources as an aid to communicate.

4.4 The Resources

As all our problems are based on robotics, we have used a Lego Mindstorms kit as a building resource for our studies with Tink-table. This kit is designed with the principles of Tinkerability and also supports tinkering ability. Moreover, by limiting the type of building resources i.e., the kit, we as researchers have been able to develop a thorough understanding of the resources and their affordances and this will help us interpret the interactions of the learners with these resources. Additionally, some semi-built models built of Lego are kept as scaffolds for the learners to understand how the components fit together. The learners also have a system that allows the learners to program Lego or even browse online resources.

5. Study Design and Preliminary Observations

The study was designed as a workshop for learners to experience tinkering by means of solving a set of problems over three days three hours each day using the Lego Mindstorm kit. The pedagogical design was operationalised into three phases with objectives as discussed in the above section. Due to the restrictions of COVID-19 and closure of the lab facility a preliminary study was conducted in an online mode where the resources were sent to the participant and set up in their location. The observer and the mentor joined via online virtual conferencing. The participant's and the mentor's video and audio were always on where-as the observer's audio and video was always off. The participant was from the 9th standard. The participant had not worked with Lego Mindstorm or any such robotics kit previously. The participant had limited exposure towards programming with a few hello world python programs. When the participant was asked how she felt about working with the Lego kit she said she wanted to build robots, but she was daunted as she did not know programming and had worked with such a kit.

We conducted the preliminary study over four days with a gap of 4 days between each study day. In Phase 1 (study day 1) the participant were to 1) use the Lego brick with any sensor deemed fit to a) measure the area and then the volume of the room b) sense primary colors and identify them on the Lego brick screen; and 2) Build a four-wheel robot that can move forwards or backward. The focus of challenge 1 was to ensure the learner experiments with Lego Mindstorms's Ultrasonic Sensor, IR / Color sensor able to understand the affordances of distance measurement, color detection, proximity detection. The other challenge focused on the building resources like beams, pegs (3 types), wheels, frames and angle joints to understand their affordances in different forms of construction and connection. The mentor was to observe the learner's trajectory towards the solution and provide prompts and direct operational information about components. It was orchestrated by the mentor using questions to trigger reflection. E.g., "*Why did you drop the previous idea ?*" encourage play to look for feasibility E.g. "*Why don't you try it out*" and direct them towards scaffolds E.g. "*See how it has been used there*?" The mentor in this phase was more of a non-contributing co-learner. In Phase 2, (study day 2 & 3) The problem to be solved by the participant was to make a bot which could 1) move front, back and turn. 2) navigate a marked grid of tiles by using control buttons on the brick and later with a cabled remote also made with the Lego Kit and 3) navigate the maze autonomously. Examples of a few objectives were to choose between a 2 motor or 4 motor design, determine the algorithm for the motors to enable turning right, left and back; a structure that allows swift turning of the bot, building the bot in a way it could be driven by push buttons built remote. For autonomous mode, estimating the distance to be traveled and find equivalent rotations to be programed and estimating the rotation direction and angle for each motor to make a left and right turn. The mentor was to observe the learner's actions on the components being used and trigger them to experiment and play by guiding them to reflect on actions of previous phase. They also did rain checks ensure flow and if stuck, for e.g., in deciding wheel configuration, they provided alternates as analogies like 3-wheel vs 4-wheel design. Mentors also directed the learner towards digital manuals for ideas and exploring functions of the components. The mentor's role in this phase was of a non-contributing co-creator. For phase 3 (study day 4) the participant was asked to build something of personal interest, and she choose to build an automatic dog feeder. The mentor in this phase took a step back and just observed the participant. Mentors choose to provide operational information and had some conversations to develop an understanding of what the learner's idea is and what they intend to do. In our case the mentor who was also the researcher who took an open interview enquiring about how she started by imagining the dog feeder in terms of Lego components, how the solution evolved over time quoting instances noted down during the observation and ending the interview by giving her a scenario and asking her how she would build the solution in terms of the Lego components.

6. Preliminary Study and Findings

The broad question of the preliminary study was, does working with Tink-table nurture behavior synonymous to operational definition of tinkering, i.e., do learners build an understanding of affordances of Lego components? Do learners think of ideas in terms of the Lego Kit components ? Does the learner trajectory involve evolution of their ideas as understanding develops? The entire online sessions were recorded in audio as well as video focusing on the interactions of the learners with the robotics kit and the mentor. The observer took notes on similar interactions. The open interview was recorded in audio and video. The recordings were used to identify episodes of interactions between the learner and the Lego Mindstorm kit and determine if the current interactions represented signs of exploration. Based on the classification of the episodes and their implications the observations were classified into a) repository of resource capabilities, b) ability to express ideas as artifacts with resources, and c) evidence of evolution from a quick fix.

The observations suggest that the participant showed signs of acquiring knowledge about the affordances of the materials in a number of instances. Though the participant preferred structural solutions, by the last day she was using and had understood the difference in the affordance of the two different motors. The participant demonstrated that she could connect the beams in different configurations by using different types of pegs to achieve different structures. Similar instances made it evident that the participant by the end of fourth day had developed an understanding of how various pieces of the kit could be used and was able to use them in various ways to achieve her objectives. During conversations with the participant internalization of form and function of Lego pieces was evident. She was also able to translate her idea of moving the motors slowly which she described in terms of angle of rotations per min and then materialized that same by controlling power that was moving the motor. Instances show that the participant was consistently thinking of improving the solution at hand which became evident as the workshop progressed. She was initially struggling with challenges and the fear of not having experience with robotics seemed to take over but after solving the first challenge of measuring the volume of the room got her the thought process going. She said she liked this approach of asking questions and trying to figure out things on her own. It was certainly more fun than someone giving instruction.

7. Conclusion

The initial observations suggest with Tink-table could lead to internalization of the Lego kit pieces and participant's ability to think in terms of the pieces when asked to build an artifact. Additionally, the participant has shown evidence of being able to externalize ideas as products made with Lego kit pieces. Progressive formalization with Lego and the way challenges have been designed will allow participants to build interest and experiment to develop an understanding of how they work and what they can do. The elements of Tink-table seem to support tinkering-based approach in addressing problems and has shown evidence that such an approach of mapping the "can do's" and "want to doo's" can be inculcated via Tink-Table. Additionally, a change was observed in participant's confidence and acceptance to this playful style of problem-solving grounding her interest into domain of robotics which initially felt daunting. This study was limited to a single participant due to the covid restrictions, but the insights are promising of nurturing a tinkering approach to problem solving with Tink-table. As facilities re-open we aim at conducting more in lab studies to also understanding the underlying processes that provide strength to a tinkerer's approach.

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