Designing TinkMate: A Seamless Tinkering Companion for Engineering Design Kits

Ashutosh Raina
IDP in Educational Technology
Indian Institute of Technology Bombay
Mumbai
raina.ashu@iitb.ac.in

Sahana Murthy
IDP in Educational Technology
Indian Institute of Technology Bombay
Mumbai
sahanamurthy@iitb.ac.in

Sridhar Iyer
IDP in Educational Technology
Indian Institute of Technology Bombay
Mumbai
sri@iitb.ac.in

***Abstract*—Tinkering is a successful approach to solving complex engineering design problems. Complexity arises due to constraints from the problem space where the available conceptual knowledge is to be applied to solve the problem. On the other hand, tinkering requires working in the problem space with the available tools and resources to find solutions to the problem at hand. Prior knowledge of affordances of tools and resources available for tinkering through a problem or ability to acquire such information in the time of need is a challenge for an engineer who is a novice at tinkering. Gathering this information from manuals and online resources frequently requires switching context, which inhibits or discourages tinkering with the unknown components. To address this challenge, we propose to build a tinkering companion, TinkMate, using a robot for interaction and augmented reality for providing essential information. From a contextual inquiry in a young engineers robotics workshop, we have found that delivering just in time information about unknown components; and providing triggers on tinkering in a seamless human-like communicative manner, encourages experimentation with components of a kit. We plan to build and test a prototype of TinkMate using an off the shelf robot ($COZMO^{TM}$) and features like just in time information (JITI) and just in time triggers for tinkering (JIT3). We would also like to study features that encourage participants and enable reflection, which has emerged on further exploration of this concept.**

Index Terms*—*Tinkering; Making ; Engineering Problem Solving; Middle School; Teaching Agents

I. Tinkering with Engineering Design kits

To tinker is to playfully experiment in an iterative style of engagement, where we continually reassess our goals, exploring new paths, and imagining new possibilities [1]. Such an approach to exploration and learning is well aligned with the goals and spirit of the progressive-constructionist tradition of [2] John Dewey's progressivism [3], Seymour Papert's constructionism [4]; and Jean Piaget's Constructivism.

Tinkering is an approach taken at various stages of solving engineering design problems. It has known to be productive [1]. When solving engineering design problems complexity arises due to available conceptual knowledge to be applied within the constraints arising from the problem space [5]. Tinkering to solve problems in engineering design requires working in the problem space with the available tools to solve the problem at hand. This approach helps handle complexities with the interplay between physical space and objects (e.g. physical space, hardware) and abstract representations (e.g. concepts). Complexities that arise due to the physical limitation of the problem or the solution are manageable when one experiments while working with physical objects. [6].

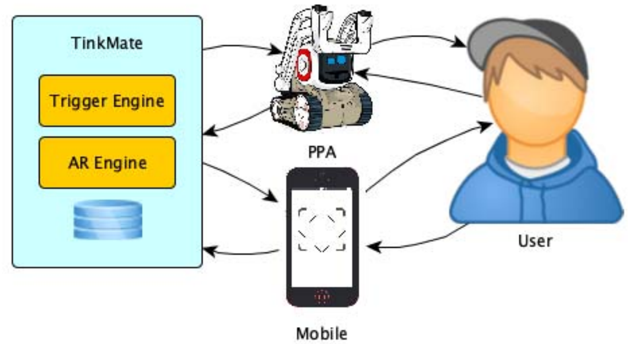

Fig. 1. Interactions between the user and TinkMate through the seamless media.

Many robotics kits that support tinkering (tinkerability) [1] are available. Ability to tinker (tinkering ability) with such kits depend on knowledge of construction, evaluation, and integration of its components and the means to acquire them as and when required. An example would be the knowledge of connecting different components of an engineering design kit like $LEGO^{®}$ $Mindstorm^{TM}$, knowing the strength of joints made between different types of components and being able to test those for the scenario they are using it. Knowledge of such intricacies enables open exploration of possible solutions using the given materials [1]. Novices lack experiential knowledge of working with the available materials or the means of gathering such knowledge as and when required. This lack limits their solutions to what they already know and may inhibit them from tinkering with all that is available. Research has provided evidence on the effectiveness of using tinkerable robotic kits like $LEGO^{®}$ $Mindstorm^{TM}$ but emphasizes on the development of explicit design instructions in worksheets to guide the students to experiment with available components while using the kits [7]. Even with the availability of such resources makers new to such kits or building resources either tend to fixate on

978-1-7281-4227-2/19/$31.00 ©2019 IEEE
DOI 10.1109/T4E.2019.00-58

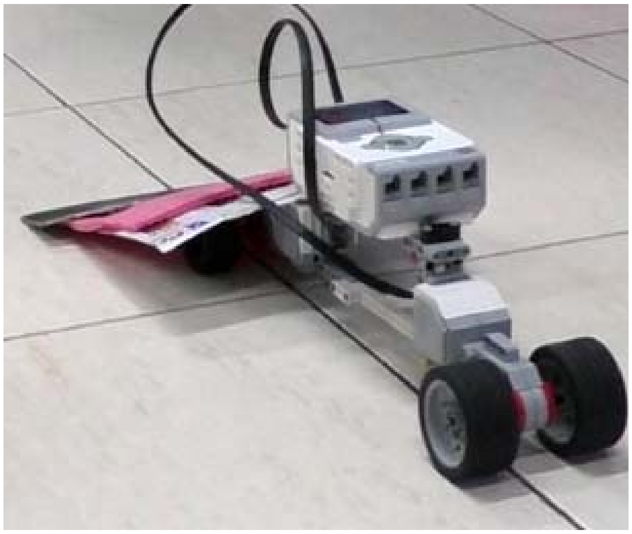

Fig. 2. A four-wheel cleaning robot designed by group 1.

step by step instructions of the sample solution [8] or as we observed in a study discussed further, ignore the worksheet and instruction manuals. Gathering information from manuals and online resources frequently requires switching context which discourages tinkering with the kit's unknown components.

It is complex and tedious to find relevant information in manuals just in time while designing solutions given the amount of information and the way it as available. Lack of knowledge of affordances of the available materials forces the students to use the available material as per their limited current knowledge about it. Ignoring the worksheets that contain information about the affordances and the use of components limits the exploration with them. As we later discuss due to limited knowledge and experience, the ideated solutions were complicated and not feasible with the material available.

II. TinkMate

To address this challenge of obtaining information we propose to design a tinkering companion for engineering design kits namely *TinkMate*, a mobile phone-based platform which provides information and triggers as and when required via two seamless mediums of interaction as shown in figure 1. Firstly it will use a tiny robot as a physical pedagogical agent (PPA) that sits on a work table allowing the user and TinkMate to interact using speech and image recognition capabilities vocally. E.g., instruction from the PPA saying *"Start simple and start making ?"* to encourage constructing with the first simple idea. It would also provide behavioural triggers like expressions and human-like body motion, as seen in figure 3. Secondly, TinkMate's phone-based augmented reality (AR) feature would augment information about the kit's components to ease exploration and experimentation with them. E.g., Information about use and configuration of a sensor like its pinout diagram, voltages, and frequencies provided

Fig. 3. Features of a physical pedagogical agent ($COZMO^{TM}$) that would enable seamless interaction between TinkMate and the user.

by augmenting it over and around the device. The ideas of TinkMate parallels to *Jarvis*, the fictional AI assistant and companion of Tony Stark a character from Marvel cinematic universe.

Literature has reported that introduction of interactive pedagogical agents who communicate with students via voice and animated behaviour show evidence of meaningful learning as the students had remembered more and transferred what they had learned to solve new problems [9]. Taking from the advantages of a pedagogical agent and adding it physically to a workspace as a robot could allowing seamless interaction via speech, visuals, and behaviour. Many areas of educational research are using robots in various roles [10] like tutors or companions and have reported merits of doing so. Moreover augmenting information on the physical object reduces the overhead of interpreting data from multiple sources and associating the object with the acquired information [11]. e.g. finding what devices could be connected to the port could just be augmented to it rather than having to search the manual for it. Many applications in education have used Augmented Reality to augment digital information on physical object [12]. Though AR and PPA could enable TinkMate to provide information seamlessly via speech and visuals, we still needed to identify features that would enable TinkMate to do so. We conducted a contextual inquiry to identify features for a seamless interactive tinkering companion that would support users with information essential for experimenting engineering design kits and equipment without searching for it extensively.

III. Contextual Inquiry to inform Detailed Design

To understand features that would be essential for a tinkering companion, we conducted a contextual inquiry in a young engineers workshop with five middle school children who had similar exposure to $LEGO^{\circledR}$ $Mindstorm^{TM}$ robotics kit. The workshop started with a hands-on introduction session to $LEGO^{\circledR}$ $Mindstorm^{TM}$. The second part of the workshop was a challenge to create a dirt cleaning robot using $LEGO^{\circledR}$ $Mindstorm^{TM}$ and a few other materials like cardboard, sponge blocks, paper cups in two hours. Figure 2 shows a robot built as a solution to this challenge. Components available for constructing the robot had a cost associated with them. One of the challenges was to build the robot with the minimum cost. The participants were divided into two teams with the same set of material for each group. Both the teams had received a worksheet with standard step by step engineering design instructions and probes for good practices of tinkering, along with an information manual for the components of $Mindstorm^{TM}$.

Group one which had two participants was assigned a Mentor Companion (MC) who assumed the role of tinkering companion. The other group was unaware of this mentor companion. MC had to provide triggers in the form of probes and information about the components of $LEGO^{\circledR}$ $Mindstorm^{TM}$ whenever asked by the participants in a seamless conversational manner. The entire study was recorded, and the videos were transcribed. The transcriptions were analyzed and categorized through the lens of seamless interactions. From this analysis, two themes emerged: -

- Just in time information (JITI) from the MC that enabled the participants to use the components of the kit.
- Just in time tinkering triggers (JIT3) from the MC to encourage them to try and experiment.

We also made a comparison between the presence and absence of MC on the above themes.

A. Just In Time Information

When the MC provided information on the affordances of the kit's components and referred to the prefabricated solution using those components, participants were seen to tinker with the affordances for their solution idea. This in-time information enabled them to derive their solution from the components that were available in the environment.

1) Illustrative example: To create a dirt cleaning robot participants of group one began with a two-wheel one motor. They were trying to add the EV3 brick over it. Upon inquiring about the connectivity of the brick, the mentor companion responded by pointing to a set of slots on the EV3 brick saying *"Can you think of a way you could use these ?"* and then referred to an activity they did using beams and frames in the workshop session which has similar slots. Similarly while programming the motor, they notice the alphabet D written on the motor code block to which they asked *"What is D in that block ?"* to which the mentor companion responded by pointing out labels on the connection ports of the EV3 Brick.

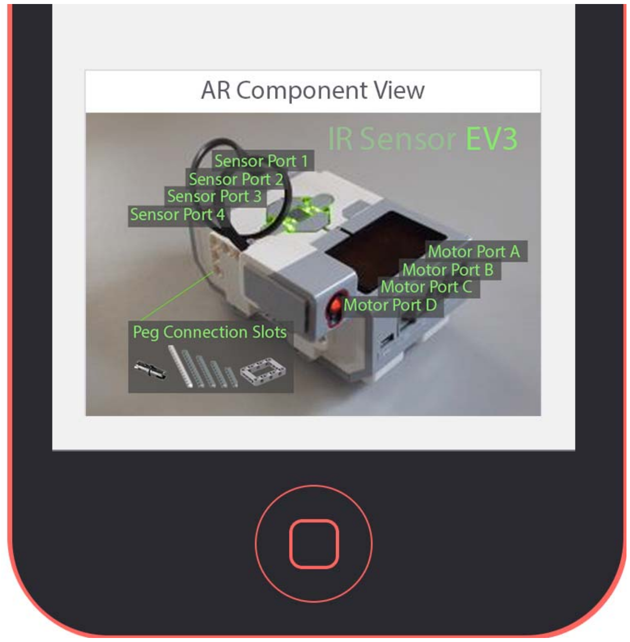

Fig. 4. Augmenting Information about the components enable ease in immediate its use.

Fig. 5. An intermediate design by group 1 with two wheels and a single motor.

2) *Design Feature:* TinkMate should provide information regarding the structural and functional affordances of the objects available for construction via the AR module like seen in figure 4

B. Just In Time Tinkering Triggers

When MC provided just in time triggers, the participants were able to differentiate and prioritize the primary goal and secondary goals streamlining the problem-solving process. Moreover, they were able to overcome their inhibitions of trying unknown component and later were seen experimenting with the affordances of the materials on their own to achieve the best possible result.

1) *Illustrative example:* Participants of group one were prompted to ignore the cost of the robot and focus on making the robot. They then worked on two primary functions, locomotion, for which they built the robot, and cleaning, for which they built the mop. In the first cycle, their robot was made of a two-wheel single motor design. They were confused between a box to collect the dust and a sponge block to wipe the dust. The MC then said *"Why don't you try both of them?"*. They ruled out the box as it was weak to sustain the weight of the robot, whereas the friction due to the sponge block inhibited the robots movement as seen in figure 5. The MC asked them to write their challenges on a note and keep it on the desk and later said *"Could you change something from your previous approach that would help overcome the challenges?"*. The participants decided to use a four-wheel two motor design by replicating the construction on the other side of the robot, which turned out to be more stable and robust. They switched a mop instead of the sponge block, which could be dragged behind the robot seen in figure 2. They kept experimenting with a different configuration of attaching the mop to clean most dust in one go.

2) *Design Feature:* TinkMate should be able to provide triggers based on best practices, and when the participants report doubt or confusion, it should probe them to experiment with all available possibilities as shown in figure 6. It could also enable the user to document information later reflect. TinkMate could provide triggers based on best practices in the beginning, and when the participants report doubt or confusion by asking them to experiment will all available possibilities. It could also be able to suggest ideas that would help participants focus on the challenges and take steps to address them one by one. Moreover, it would be able to document information for the participants to be able to reflect like making logs via speech and taking snapshots of the current state of the solutions. This feature will enable the participants to reflect on the decisions and action they have made.

C. Comparing presence and absence of MC

Seamless availability of JITI from the MC encouraged the participants to tinker with different components of the kit whereas difficulty of obtaining such information during ideation was seen to discourage usage of new components. Secondly, JIT3 guided participants in managing complexity

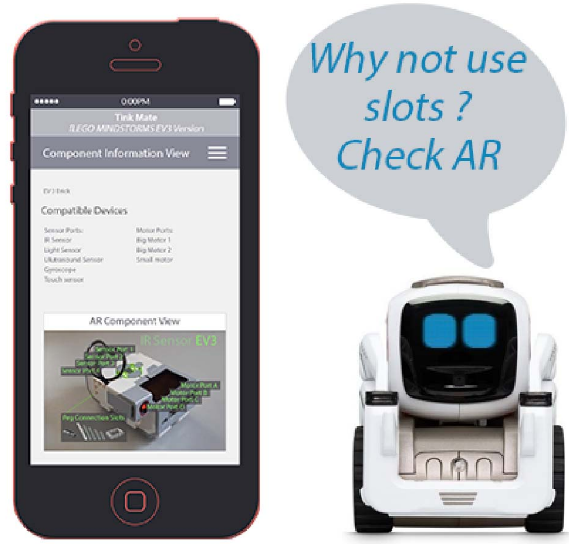

Fig. 6. PPA provides audio, visual and behavioural triggers complemented with information from the AR to aid the use of kit components.

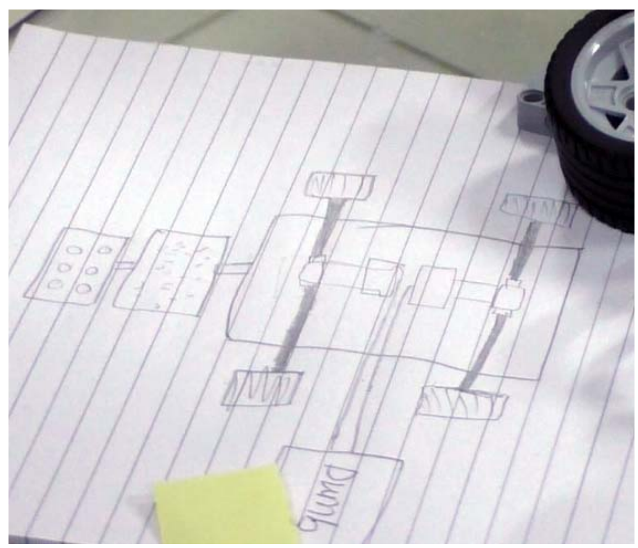

Fig. 7. Conceptual design made by group 2 not aligned with the available components.

and encourage participants to tinker with the available components whereas in its absence participants kept switching between different functions and requirements while coming up with a conceptual design of the solution which was not aligned to components available. Finally, none of the groups used the manuals, or worksheets even though they were reminded to refer to them.

1) *Illustrative example:* Group two made a conceptual sketch considering just the motors and the EV3 brick, as seen in figure 7, constantly trying to keep the cost low hence failing

to realize the structure of the robot. Later they kept using cardboard to create the structure and connect these components with a two-sided adhesive tape as seen in figure 8. They kept discussing their conceptual design to which they were fixated and worried about the cost. Eventually, they failed to finish the challenge in the given time. On enquiring about the reason for not using the beams and frames, they said *"We would have to create a container using many beams and mount it on the motors to place the EV3 brick in it, and that would cost a lot."* They were unaware of the function of slots on the EV3 brick. Upon asking the groups about the worksheet, they said *"We were too busy working on the robot, so we did not get time to fill the worksheet."*

2) Design Feature: The seamless conversational nature could help the participants tinker. Though this could vary between a human companion as used in this study and a robot, something we would want to evaluate next.

Detail Design Decisions: Based on the themes of the contextual inquiry TinkMate should be able to provide information on the structural and functional affordances of the kit components and provide triggers on best practices of tinkering and experimentation using AR and APP as listed in Table I

Fig. 8. Group 2 connecting the motors and mounting the EV3 brick with adhesive tape.

D. Further Exploration

To develop the initial proof of concept for TinkMate, we considered getting an off the shelf educational robot. We surveyed all the available candidate options from different manufacturers in a similar price range based on the features like a small form factor to ensure its subtle presence in the working environment and not become a distraction; ability to communicate via speech with the user to provide a seamless interaction; ability to take pictures for AR and image processing engines of the TinkMate; Ability to demonstrate human-like behaviour via visual and behavioural animations; and to be able to wirelessly communicate with a mobile device; freedom to obtain the data from the robot and program its behaviour using an API. After evaluating the candidates on the criteria as mentioned earlier, we choose to use $COZMO^{TM}$ by $Anki$® technologies [13] as it satisfied all the criteria as mentioned earlier.

We explored $COZMO^{TM}$ for a month. We hardcoded some triggers to understand interactions that can be made using its features. For example, triggers to encouraging experimentation, expressions that show frustration to discourage some behaviour. $COZMO^{TM}$'s features of being able to express emotion is one of its key strengths as a companion robot. When people have been very positive about its interactions but these observations also suggest it might lead to distraction towards the interaction. Though these distractions might reduce with consistent exposure as a future perspective, we plan to evaluate the same.

Motivating participants, while experimentation is another point that emerged while interacting with tinkerers on the use of $COZMO^{TM}$. This idea emerged in several interactions with the emphasis on doing this when experimentations. One of the tinkerers said *"Frustration due to failed experiments is common with tinkering. What one needs is motivation to look at the failure to develop a better understanding of a system."* This aspect seems to be an essential part, as similar instances were even observed during our study. In group 1, the participants were initially struggling to think of a solution and requested the MC to change groups. The MC motivated them to try their ideas once, and the participants were able to proceed. Initially, when the experiments would fail, they would come to the MC and tell about the failure to which the MC would suggest them to write these challenges and then think about an alternate idea. The participants would come up with an idea and experiment which helped them move forward. Once the first version of their robot was ready, they were following this process for all other challenges. This observation not only emphasizes the importance of motivation but also shows the importance of reflection. Hence we plan to incorporate these in the future and study them explicitly for TinkMate.

IV. FUTURE WORK

The contextual inquiry has provided us with evidence for seamlessness as an essential characteristic for a tinkering companion which contributes to its effectiveness. This study has also provided us with some features that are essential for such a seamless tinkering companion. The effectiveness of using TinkMate (PPA with AR engine) as a tinkering companion is something we plan to evaluate next. We will use the proof of concept of the TinkMate application to understand the level of seamlessness that could be achieved using TinkMate and its impact on the use of engineering design kits. We would also like to study interactions of tinkers with $COZMO^{TM}$

TABLE I
SUMMARY OF DESIGN FEATURES DERIVED FROM THE CONTEXTUAL INQUIRY.

	Information	**Medium**
JITI	Information on structural and functional affordances	Augment with AR and trigger usage with PPA
JIT3	Triggers on best practices	Triggers and Probes with PPA
	Triggers for experimentation	Triggers and Probes with PPA and affordance using AR for experimentation

as a companion, especially to understand if certain behaviours or features could become potential distractions and to what extent.

Further, we would like to study the impact of using a physical pedagogical agent during experimental failure. We would also like to explore features in TinkMate that would enable it to encourager the tinkerers to carry and facilitate reflection. The findings from this study will also help us make design decisions regarding the user interface and user experience with TinkMate.

ACKNOWLEDGMENT

The authors would like to acknowledge Navneet Kaur, Aastha Patel and Prof. Chandan Dasgupta for allowing us to be a part of the young engineer's workshop and sharing resources.

REFERENCES

[1] M. Resnick, *Lifelong Kindergarten: Cultivating Creativity Through Projects, Passion, Peers, and Play*. MIT Press, 2017.
[2] J. Piaget, "To understand is to invent: The future of education," 1973.
[3] J. Dewey, "The theory of inquiry," *New York: Holt, Rinehart and Wiston*, 1938.
[4] S. Papert, *The children's machine: Rethinking school in the age of the computer.* ERIC, 1993.
[5] C. L. Dym, *Engineering design: a synthesis of views*. Cambridge University Press, 1994.
[6] C. L. Dym, A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, "Engineering design thinking, teaching, and learning," *Journal of engineering education*, vol. 94, no. 1, pp. 103–120, 2005.
[7] J. Ringwood, K. Monaghan, and J. Maloco, "Teaching engineering design through lego® mindstorms," *European Journal of Engineering Education*, vol. 30, no. 1, pp. 91–104, 2005.
[8] A. Raina, S. Murthy, and S. Iyer, "Help me build: Making as an enabler for problem solving in engineering design," in *2018 IEEE 18th International Conference on Advanced Learning Technologies (ICALT)*. IEEE, 2018, pp. 455–457.
[9] M. E. Karim, S. Lemaignan, and F. Mondada, "A review: Can robots reshape k-12 stem education?" in *Advanced Robotics and its Social Impacts (ARSO), 2015 IEEE International Workshop on*. IEEE, 2015, pp. 1–8.
[10] Y.-W. Cheng, P.-C. Sun, and N.-S. Chen, "An investigation of the needs on educational robots," in *Advanced Learning Technologies (ICALT), 2017 IEEE 17th International Conference on*. IEEE, 2017, pp. 536–538.
[11] M.-B. Ibáñez and C. Delgado-Kloos, "Augmented reality for stem learning: A systematic review," *Computers & Education*, 2018.
[12] Y.-H. Ching, Y.-C. Hsu, and S. Baldwin, "Developing computational thinking with educational technologies for young learners," *TechTrends*, pp. 1–11, 2018.
[13] Anki, "Cozmo the educational robot with a personality," 2019, https://www.anki.com/en-us/cozmo.