DESIGNING AND MAKING ROLLER COASTERS BY INDIAN MIDDLE SCHOOL STUDENTS

Anisha Malhotra-Dalvi*, Adithi Muralidhar*, Arundhati Dolas, Rupali Shinde and Sugra Chunawala
Homi Bhabha Centre for Science Education,
Tata Institute of Fundamental Research, Mumbai, India
anisha@hbcse.tifr.res.in, adithi@hbcse.tifr.res.in

The current article details our observations from two workshops with grade 9 students, working in groups, designing and making a paper roller coaster. The preliminary analysis of our observations indicate that designing an activity around roller coasters has huge potential in terms of giving students first-hand experience of designing, open-ended thinking, exploration and modelling. The activity enabled communication and collaboration between members, engaged them in planning, designing, model-making and executing design ideas.

Keywords: *design education, modeling, making, roller coasters, collaboration*

INTRODUCTION

Maker-centred learning provides opportunities to learners to acquire both critical and creative thinking skills through creating, designing, making and tinkering activities. These activities promote active participation, self-directed learning and encourage taking up of challenges as creative learning opportunities (Clapp, Ross, Ryan & Tishman, 2016). In the context of design problem-solving, a typical maker-centred activity would involve ideation, material exploration and manipulation, mock-ups, model-making, and prototyping. Studies with practising designers have shown frequent use of mock-ups and rapid prototyping (Hess & Summers 2013; Deininger, Daly, Sienko, & Lee, 2017) at different stages of design process to benefit the final outcome. Amongst children, the process of model-making has also been reported to aid in externalising and verbalising ideas that might otherwise be difficult to communicate (Yrjönsuuri, Kangas, Hakkarainen, & Seitamaa-Hakkarainen, 2019).

Context of this study

Roller coasters (RC) are fun rides to be on. They have often been the object of interest for children, even when they have never experienced riding on one. Making and designing RCs is not new to educators (Cook, Bush & Cox, 2017; Jones & Jones, 1995; Ansberry & Morgan, 2008). One finds a variety of activities on science (typically concepts of potential and kinetic energy, velocity/speed, gravity and laws of motion) and engineering design surrounding RCs. However, in the process of implementing such activities in a classroom setting, learners tend to concentrate on the procedural aspects of making their designs, instead of exploring relevant science content and design principles. Vattam & Kolodner (2008) refer to this tendency as the "design–science gap". One may also argue, that procedural prototyping (for example template based or ready-to-use kits) may not be ideal for children who are novices in designing as it might not facilitate learning and mastering fundamental design and engineering skills such as measurement, precision, estimation and approximation (Choksi, Chunawala & Natarajan, 2006).

Although, activities pertaining to designing and making RCs are quite popular in school science education, they are not documented with Indian students, especially from a design perspective. In this exploratory study, we share our observations from two design and technology (D&T) workshops which were conducted with the aim of introducing students to the iterative design process from conceptualisation to making and evaluating.

METHODOLOGY

Two stand-alone workshops of approximately 3.5 hours each were conducted a day apart with grade 9 students. The workshops were planned with a focus on engaging students with design exploration, planning and making skills, collaboration, communication and evaluation.

Participants and Data Collection

The workshops involved Grade 9 students (age group 13-14 years) of Jawahar Navodaya Vidyalaya (JNV) schools from 3 Indian states (Gujarat, Maharashtra and Goa). JNV schools are central government residential schools spread across India, where the medium of instruction is both Hindi and English. There were two batches of students. One batch had 29 (8G, 21B) students and the other 31 students (19G, 12B). Students were from rural, semi-rural and urban backgrounds and many were unfamiliar with others in the batch. Student groups were formed by a random chit-based system. Most of the groups happened to be mixed gender groups with 4-5 students in each group. In total, there were 12 groups which have been named as G1, G2, G3, and so on, in this paper.

Data sources: Field logs from 4 facilitators, informal and formal interactions with students, students' drawings, the RC models made by students, photographs and videos, student presentations, and the worksheets filled by students of workshop 2, served as sources of data.

Procedure, Design Brief and Materials

The workshops were planned to engage students on a D&T task in a playful manner. Workshop 2 (W2) was re-structured after reflecting on the learnings of Workshop 1 (W1). Both workshops started with an initial discussion of students' ideas about D&T. This was followed by a brief 10 minutes presentation on D&T with a focus on iterative and collaborative nature of design. Subsequently, students were involved in the following steps: 1) Practising basic skills (paper folding techniques) needed for the RC design challenge; 2) Brainstorming, planning and making rough drawings of their RC design; 3) Building or Making the RC. 4) Testing and evaluating their RC model by using a marble and revising the models. 5) Demonstrating their final working RC model and communicating it to their peers. There were some differences in the ways the 2 workshops (W1 & W2) were conducted. These differences were: initially, information about the design task was unknown in W1, while it was known in W2. In W1, facilitators engaged the whole class together for making different RC tracks, while in W2, three workstations were setup simultaneously to demonstrate the same. Use of funnel and wide loop was mandatory in W2, but not in W1. A worksheet for reflection was given only to students in W2.

> *Design Brief*: *Imagine you are a roller coaster design team competing to design a new and exciting roller coaster ride for a playground. Your task is to design and build a mini paper model of the ride using the paper folds taught to you. You have to test your ride with the marble provided. The specifications are: 1) The entire roller coaster must fit on the base provided; 2) The marble on your ride should travel for at least 4 seconds; 3) You have to use at least 1 pillar, 1 loop, 1 straight track and 1 L-shaped track. Also, 1 wide loop and 1 funnel (specific to workshop 2); 4) It should be a self-supporting model; 5) Marble should travel from start to end without any external interference.*

Materials provided to students: Coloured paper, scissors, glue, stapler, sticky tape, pencil, scale, a base box with dimensions: length=45cm and width=50.5cm (Workshop 1) and length=29cm and width=38cm (Workshop 2).

OBSERVATIONS AND FINDINGS

Our analysis focused on design process, specifically exploration, generation of ideas, modelling and collaborative designing. Design process was analysed using students' sketches, their final RC models, student discussions and conversations as reflected in our field notes, and photo documentation of the workshops. Insights for evolution of ideas were drawn from students' design explorations and negotiations. Collaborative designing was analysed in terms of distribution of responsibilities and use of verbal and non-verbal communication modes.

Design process and evolution of ideas

Building of a RC as a design challenge was received with a lot of enthusiasm by students. They were focused while learning new paper folding techniques and curious to know how these paper folds can be placed together to make a working RC. After the initial session of demonstration and learning folds, the groups were involved in making a working model, and this required planning and teamwork. The design challenge involved ideation, design and planning, making and testing. D&T education places emphasis on developing technical abilities of students in addition to imparting essential skills like modelling. Stables and Kimbell (2000; 2006) stress the strong interaction between mind and hand during design and making activity, indicating that they are inseparably linked. Harrison (1992) argued that in schools, most making should in fact be modelling. He categorised the purposes of modelling as i) aids in thinking, ii) communicating form or detail, and iii) evaluating a design or selecting its features.

The process of constructing the roller coaster: All the teams were encouraged to make a design sketch of their RC first and plan the requirement of parts. However, we observed that only few groups chose to sketch before starting to make the RC. Prior to students making the models, facilitators had demonstrated two different approaches of building a roller coaster. First, making the path with various parts and later give support with pillars and second, start with building a skeleton structure with pillars only and later add tracks to design the RC. The students had the freedom to choose either option as their approach for designing and execution. Most groups began with the second approach but moved on to using a combination of both methods. One of the major constraints that seemed to influence students' design approach was being aware of the limited time in hand. As a result, most of the teams (G1, G2, G3, G6, G8, G9, G10, G11, G12) simultaneously started making a minimum set of pillars, straight tracks and at least one L-shaped track. Only G5 approached the design task with one task at a time, that is, all members made pillars first, followed by making tracks. Once the teams made a few parts ready for use, tasks were distributed amongst members to assemble the RC model. Estimating the number of pillars they would require to build the RC was important and team members spent considerable time making pillars accurately. Making the paper folds especially the loops required skill and teamwork. It involved careful measurement, accurate cutting, folding and sticking the folds together to form a loop. The entire exercise of measuring and joining of parts was essential in holding the entire weight of the RC. Most groups wanted to make their RC such that it would to be able to hold the marble for the longest time. But they struggled with ways to make time extenders. With constant explorations and testing, they were able to overcome these challenges and came up with a variety of ways to extend the time spent by the marble on the RC. Irrespective of the approaches used, we observed that all groups managed to successfully complete the task within the stipulated time (3.5 hours).

The use of sketches: In design research, sketching has been reported to play a crucial role in generating, developing and communicating ideas (Goel, 1995). However, children may not consider sketching as useful as it is considered by design professionals (Rogers, 1998) and children may shift to exploring 3-dimensional modelling for prototyping and ideation (Welch, 1998; Rowell, 2002; Hope, 2005). Our observations align with the aforementioned. It seemed that the initial use of 2-dimensional sketches for the RC model was not necessary for children; as some groups (G1, G3, G7, G8, G10, G11) retained only a few parts (like the start and end) from their sketch in the final models. Interestingly, we observed G3 sketched and planned on the base provided to them, in addition to a rough sketch on paper. They marked positions for pillars on the box, estimated the number of pillars required and then started making pillars. Two groups (G9, G12) reported that their final model was completely different from their initial sketch. It is evident from their sketches and respective models that none of final models was the same as the initial design sketch. Our observations indicate that in this making task, students preferred 3-dimensional modelling over sketching for thinking, planning, communicating and developing design ideas.

Design exploration and negotiating challenges: Research studies performed with practising designers have shown frequent use of mock-up models and rapid prototyping aids in early identification of design issues, discovering opportunities, conceptual design and eliminating less promising solutions (Hess & Summers 2013; Deininger et al., 2017). Children can also use prototypes as thinking aids for both refining their models and developing design ideas (Yrjönsuuri et. al, 2019). As the students built their RC models, they explored design possibilities, discovered issues with their initial designs and invented novel solutions sometimes through trial-and-error and material manipulations. During the modelling process, they encountered several challenges, such as placement and joining of the parts. At times, the marble would get stuck or would not jump from one track to the other as estimated or it would derail from the track due to excess speed. Through continual revision and testing, however, students were able to evaluate and resolve these problems. Groups spent a considerable amount of time to figure out the size, placement and adaptability of parts such as loops and tracks on the RC model. The procedure to make a funnel or a wide loop had not been demonstrated by the facilitators in workshop 1 (W1). Hence, it was not a part of initial design sketches in any of the groups who participated in W1. But as they progressed with making RCs many students insisted on having funnels and wide loops in their RC model (which they had seen in the demo model). Thus, G10 had initially planned to put one wide loop, instead they placed an S-shaped loop made by combining two wide loops. For G12, the marble did not move through the RC track and got stuck in between. They often had to make adjustments in positioning of pillars, in the wide loop (they had to remove and again stick it properly) to maintain a smooth flow of marble. Therefore, children constantly used their models for exploration, design ideation and evaluation.

Regarding the various technical and design hurdles that students faced, we observed that for the most part students were able to resolve these by themselves without the facilitator's intervention. Students were actively engaged in the task and skilfully made all the different tracks and carefully placed them on the base provided. An example where students did approach the facilitators is described in the case of G3. A boy from G3 showed one of the facilitators a curved loop that the group made and inquired, "I*f I put the marble on this normal loop, then it falls… so, how should I make it (the loop)?*". This inquiry could be a result of knowing the possibility of another type of loop (a wide-loop, which was shown in the demonstrated models designed by the facilitators, but was not taught to students in W1) and the inability to make the same. Here, the process of making, testing, evaluating and not being able to achieve what was desired, made the team members seek our guidance and look for other options. Overall, wide-loop was found to be one of the most difficult parts to make by the students in both the workshops. While making the wide-loop, students got confused between the wall and base of the track and often ended up making a regular loop (U or C shaped) instead of a wide loop (G2, G3, G5, G8, G10). It is only when they tried to stick it to their RC structure, they found mistakes in the making of the wide loop.

G3 also faced a technical glitch and the group members proposed and discussed potential solutions to address it (Figure 1 and Transcript 1 below from field notes). Interestingly, the group discovered that lack of smooth rolling worked in their advantage by increasing the time the marble spent on the track.

Boy 1: The marble is not rolling smoothly from here (gestures by pointing at a location) to here (gestures by pointing at another location).
Girl: Shall we increase the height of this pillar?
Boy 2: But we have already stuck the pillar.
Girl: We need to somehow give it a lift here (pointing at the blue corner)
Boy 3: We can't add pillar here (gesturing at blue corner). [this could be since the design brief insisted on restricting the RC model to the base provided].
Girl: Ok, let's first finish this part (gesturing the track ahead of their problem) and come back to this.

Transcript 1: Adapted from Field Notes.

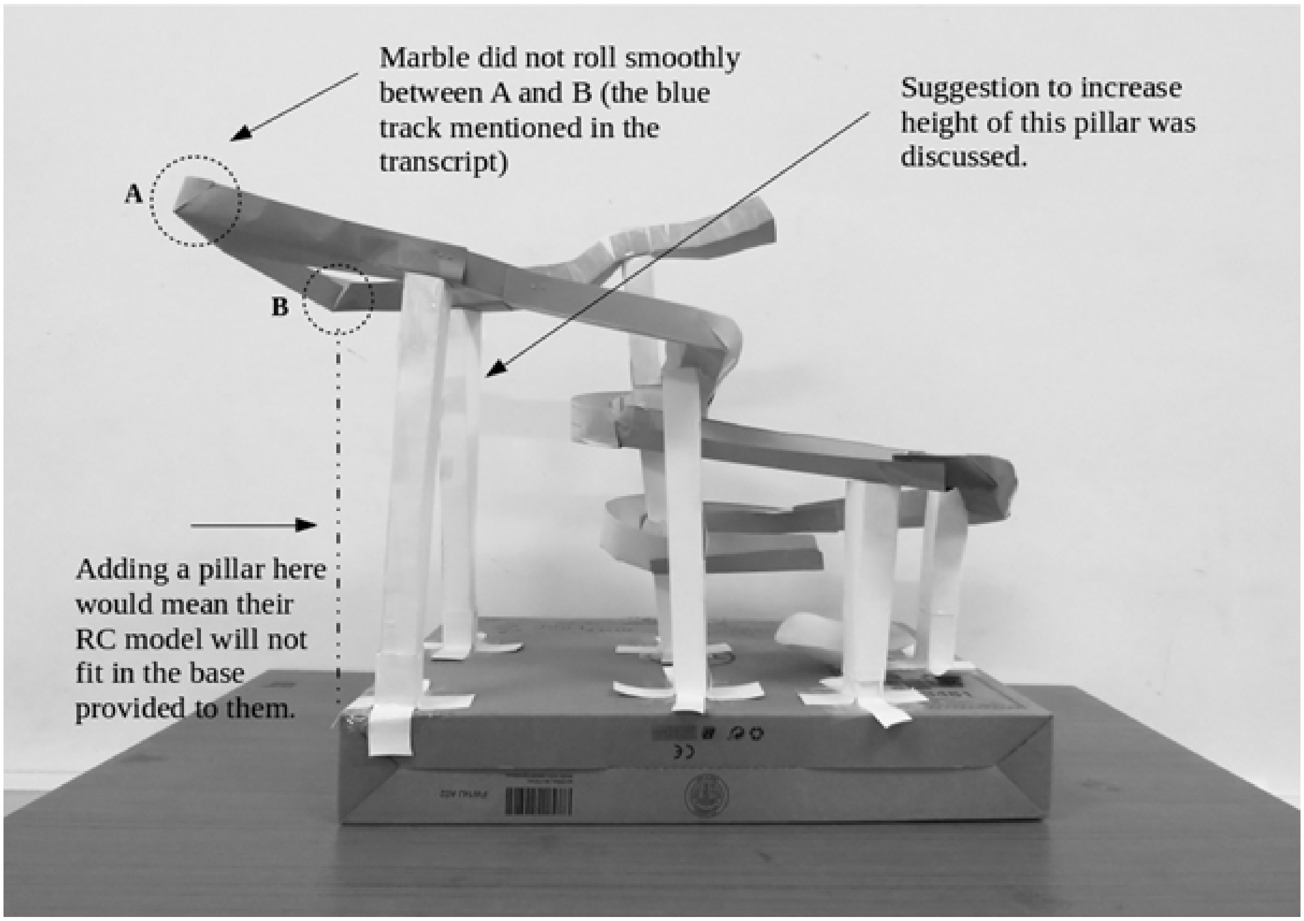

Figure 1: Roller coaster model of G3

Elements of novelty: Within the context of this workshop and our analysis, student explorations and design ideas were considered 'novel' if the ideas were unique (design and use of new elements which was not demonstrated by the facilitators) within the group of participating students i.e. 'local novelty'. Students brought in various novel elements in their RC model under different circumstances. For example, G1 realised they had missed one of the design brief requirements in the RC, a loop. Rather than redoing or moulding the entire RC, they added an innovative element in their design; a disconnected stand-alone half-arc to capture the marble towards the end. The force with which the marble would fall there, would make it go up the arc for a few centimetres, thus decelerating and then the marble would roll back down the arc into the funnel. This, according to the students, added approximately 1.5 seconds to the time spent by the marble on the RC. Another incidence involved G3 realising that their model had a flaw (see Transcript and Figure 1) in one of the tracks, which they later intentionally retained because it increased the time considerably, the marble spent on the RC. Additionally, G3 also explored making a different type of a pillar, in which they inserted one pillar into the other so as to make it adjustable as per the requirements but decided against using it.

More instances of novel elements include; G7 experimenting with a unique use of the pillar structure to drop the marble and make it an interesting starting point. The 'uniqueness' entailed using a pillar as a track. They also made a few hexagonal pillars, and used a track to strengthen another track. G6 made an extended flap which would capture the marble in a compartment. G10 had included a triangular pillar in their model. Some groups also made multiple wide loops (G8, G9, G11, G12) that increased time or introduced twists around the pillar which led to adding levels in the RC. Some models were designed to have intentional breaks in the tracks leading to the marble dropping onto another part (G1, G10, G11, G12). Groups G5, G6, G7 and G9 made RCs which they thought may not keep the marble on for long. Hence, they generated ideas on time extenders and made a variety of speed-breakers (G5, G9), flaps (G9) and multiple staircases (G5, G7, G9). We also saw time extenders being used by other groups (G2, G10). Interestingly, students in G5 and G6 decorated the RC base with the remaining coloured pieces of paper which according to them, added to the aesthetics.

Modelling and collaborative designing: During collaborative designing, design ideas become visible for joint evaluation and development through materialisation and model making (Ramduny-Ellis, Dix, Evans, Hare, & Gill, 2010). Prototyping can be used as an effective method to externalise ideas that might otherwise be difficult to imagine, explicate and verbalise (Yrjönsuuri et. al, 2019). In this section, we showcase instances of how a shared goal of co-creating an RC model encouraged collaboration between group members through material handling, and making and assembling parts of the RC model. In this section, we elaborate on two important aspects of collaborative designing. One was the distribution of tasks and responsibilities and the second was the use of verbal and non-verbal modes of communication. The task of making a working RC in a group within time constraints and the material manipulation and assembling required a lot of coordination and teamwork. Lahti, Kangas, Koponen, and Seitamaa-Hakkarainen (2016) have reported linkages between model making and materials with division of labour. Particularly, we observed instances where a student was involved in a making task, and either requested help or was offered help to achieve the task (G5, G11). In most of the groups, leaders emerged implicitly or explicitly, and delegated responsibilities, built a consensus among team members and steered the group closer to their final design.

Figure 2: Left- The girl gestures to her group members, the ideal height of the second pillar (G6); Right- Students move the free-track up and down to check for the right incline, before sticking it to the pillar (G11).

The RC model-making acted as a central point of focus which facilitated and mediated discussions through the use of verbal and non-verbal modes of communication. Härkki, Hakkarainen and Seitamaa-Hakkarainen (2018) have noted co-working on building models helps in verbalising ideas, and the role of non-verbal modes of communication, such as sketches and gestures does so as well. They emphasised that gestures play a dynamic role in creating and shaping design ideas leading to further refinement of design ideas. There were numerous instances during the stages of planning, making and presenting, where students resorted to a variety of non-verbal modes of communication, mainly in the form of gestures to propose solutions and communicate problems (Figure 2). Students also used gestures to convey emotions of excitement or disappointment when their model 'worked' or did not.

DISCUSSION

Though the idea of making paper RCs is not new to educators, one has not seen it in practice in Indian settings nor has this been documented. These workshops offered a glimpse of how such a D&T activity can be planned for a class size of around 30, for a time period of around 3.5 hours. Students engaged in open-ended design problem solving which led to the creation of a working model of RC. All groups successfully fulfilled the requirements mentioned in the design brief by acquiring and strategically using paper folding and modelling skills. In fact, no two models were the same and all the models could hold the marble for more than 5 seconds. Our observations revealed that students used a combination of approaches when constructing the RC and did not adhere to their initial sketches much. They preferred 3D modelling over 2D sketches to ideate and communicate. This is perhaps a difference between the way professional designers and school students approach a design problem. More opportunities thus may be built into the structure of the workshop allowing for material exploration and manipulation.

Previous studies have indicated that students often refine their design over the course of planning and making (Khunyakari, Mehrotra, Natarajan, & Chunawala, 2006). Our observations also indicated that students extensively explored various design options while making and testing, negotiated and overcame challenges, and brought in novel elements to their RC model. Lastly, the challenge of model making, and group work resulted in students using verbal and non-verbal modes of communication, which aid collaboration (Jeong & Chi, 1999; Mehrotra, 2008). When students perform such open-ended activities, it helps them: in constructive investigation, to overcome their preconceived notions, to accept and assess mistakes and to rethink or rework on ideas. Though preliminary, the analysis provides insights into planning design problem-solving activities for school students. Observations from this study can also be useful for teachers who wish to implement exploration-based making activities in schools. The work can be extended to understand if and how students reflect on the process of designing and arrive at generalist conclusions about factors that worked in their successful completion of the task.

ACKNOWLEDGEMENTS

We would like to thank all the students of grade 9 who participated so enthusiastically in our workshop. Thanks to the Jawahar Navodaya Vidyalaya management and the teachers who accompanied the students.

Thanks to the anonymous reviewers whose comments greatly helped to improve the manuscript.

We acknowledge the support of the Govt. Of India, Department of Atomic Energy, under Project No. 12-R&D-TFR-6.04-0600.

Notes

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https://www.instructables.com/id/Paper-Roller-Coasters-/

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