Collaborative Uncertainty Management While Solving an Engineering Design Problem

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Abstract: Uncertainty plays a crucial role in making engineering design decisions. It directly impacts both the design process and the final design output. It is important for learners to develop the skill of managing uncertainties effectively. However, there is a lack of research investigating how students manage uncertainties during a collaborative design process and how effective uncertainty management skills may be developed in the learners. In this paper, we present the results of a pilot study investigating how middle school students collaboratively manage uncertainties while solving an engineering design challenge. We also discuss issues related to the management strategies used and reflect on how these issues can be addressed using a computer-supported collaborative learning environment.

Introduction

Engineering design problems are ill-structured and encompass uncertainties that arise due to the open-ended nature of the problems as well as the collaborative design process (Dym, Little, Orwin, & Spjut, 2009). In this paper, uncertainty refers to the cognitive feeling that encompasses subjective experiences of wonder, doubt or being unsure (Clore, 1992). The ways in which the uncertainties are managed collaboratively affect the overall design process and thus have implications for how and what students learn about engineering design (Jordan & McDaniel Jr, 2014). In this paper, we investigate how middle school students manage uncertainty while solving an engineering design challenge in a collaborative environment. We also discuss issues related to the management strategies used and reflect on how these issues can be addressed in a computer-supported collaborative learning environment aimed at developing learners' uncertainty management skills.

Method

In this pilot study, we conducted an after-school robot design workshop for seventh-grade students in a metropolitan city in India. Five seventh grade students (three girls and two boys) participated in the study. We divided the students into two teams randomly. One team (Group A) consisted of two students (one boy and one girl) and the other team (Group B) consisted of three students (two girls and one boy). The workshop had two parts; first four hours consisted of basic training with the LEGO Mindstorms™ kit since students did not have any prior experience with it. In the next four hours, teams solved a design challenge competing with each other. Teams had to design a robot that cleaned at least two of the following materials- paper bits, LEGO™ pieces, water droplets, eraser dust, and pencil dust. They used LEGO Mindstorms™ kit and materials provided to them, such as mop and sponge, to construct the robot. Every construction material had an associated cost. The teams were asked to optimize the cost of their design.

We collected data from each team using audio and video recorders. We also conducted semi-structured interviews at the end of the design challenge and collected students' design artifacts and the workbooks given to them for taking notes and making sketches. We transcribed the video and audio data and noted the verbal conversations, gestures, interaction with objects, and gaze, in the transcript. Next, we analyzed the transcripts using the content analysis technique (Mayring, 2015). To ascertain the occurrence of uncertainty we used the coding scheme developed by Jordan et al. (2014), which focuses on the use of *hedges, probability statements, hypotheticals, questions, and various nonverbal* indicators during student interaction. Next, we iteratively analyzed the uncertainty episodes to identify various management strategies based on our previous work (Kaur & Dasgupta, 2018).

Findings

Teams reduced, suppressed or maintained the uncertainty during the design process. Strategies used by teams for reducing uncertainty were– *Analysis, Argumentation, Brainstorming, Experimentation and Trial & Error, Ask and Apply, and Observe and Replicate*. Students suppressed uncertainty by *ignoring* them. Strategies used by teams to maintain uncertainty was– *Delay Action.* Comparing the two teams, we found that during the entire design process, for group A, there were 31 episodes of uncertainty, whereas for group B, we found 40 episodes where the team faced uncertainty. We found differences in the way the two teams managed these uncertainties.

Group A used the *Ask and Apply and Ignore* strategy the most (23% each), followed by Experimentation and Trial & Error (19%). Group B used the strategy of *Analysis* the most (22%), followed by strategies like *Brainstorming* (20%), and *Argumentation* (17%). Use of strategies like *Delay Action* and *Ask and Apply* was negligible (2% each). We now share representative instances of how these strategies played out, and then discuss possible computer-supported solutions to scaffold these strategies.

Analysis

This strategy includes actions like making sketches and diagrams, troubleshooting, and separating available information into parts. For example, consider the following episode:

> *B1: We will have two motors like this, here is the sponge and the wipes [pointing to the sketch], and that brain [referring to the EV3 brick] will be dragging behind.*
>
> *B2: I am still not clear…wouldn't it hurt the brick, we can put it on the top. And how will we attach that sponge and the wipes? And where are the wheels? How many do we need?*
>
> *B1: We need four.*
>
> *B2: Putting these on the sides [referring to sponge and wipes in the sketch] will not clean the trash completely. We also need to add a dustbin kind of thing to collect the trash.*

Here, group B learners B1 and B2 reflected on one of the alternatives sketched by them. They were figuring out how to attach different components of the robot (the motors, EV3 brick and cleaning materials) using the analysis strategy. While analyzing, the team identified issues with the design like the problem of dragging the brick, the problem with the sponge and wipes attached on the sides, etc. The strategy helped the team establish a function of garbage collection. It also gave rise to new uncertainties like where to put the EV3 brick, how to collect the garbage, and where to attach the sponge and wet wipes, thus expanding their problem space and opening opportunities to make their design even better.

Argumentation

This strategy encompasses the process in which two or more engineers engage in a dialogue where arguments are constructed and critiqued. For example, consider the following episode:

> *B1: Do we really need to make a bottom? I don't think so. [Referring to a support that team is trying to build to hold EV3 brick in the Robot].*
>
> *B2: We need it because the surface will be uneven.*
>
> *B1: No, because all the wheels we are using are of same height.*
>
> *B2: But above the surface will be rough and the brick will keep falling down.*
>
> *B1: We can do something, may be just tape it, because the bottom would be very costly.*
>
> *B2: Ok. We can try it.*

Here, group B used the argumentation strategy for dealing with the uncertainty related to how to build sturdy but cheap support to hold the EV3 brick. The strategy likely helped in resolving conflicts and building consensus among the teammates. It also helped in making informed decisions and lead to clarification and reduction of doubts and misconceptions.

Experimentation and Trial & Error

This strategy includes systematically testing option(s)/ ideas or engaging in Trial & Error method. For example, consider the following episode:

> *A1: Should we just stick the wipe and sponge on the sides, or back or in front? Or should we just use sponge at the bottom and wipe at the back. I am not sure which will work better.*
>
> *A2: Umm... I don't know, let's try them up.*

Here, in group A, while figuring out which design would help in cleaning the trash better, students started by testing their first idea, i.e., attaching sponge and wipes on the left and right side of the robot. To get the desired output, they used Trial & Error to check if anything worked. The team then tested another idea of using the sponge at the back. They did not test any further idea since they got a satisfying result.

Brainstorming

This strategy refers to collaboratively generating ideas around a specific common problem. For example, consider the following episode:

B1: We can fold the wipes.

B2: We can also cover the sponge with the wipes.

B1: We need a broom kind of thing and this [pointing to the cleaning wipes] will go wiping behind.

B3: Or a wipe followed by sponge. It will first do dry cleaning and then the wet cleaning.

B2: We can cut the wipes and the sponge to place it on both sides.

Here, group B was faced with the uncertainty about how to use the additional cleaning materials given to them. They brainstormed different ideas which helped the team generate multiple ways of using the wipes and the sponge. This helped the teammates understand each other's perspectives and think of ways by which they can incorporate ideas of other team members. However, teams seemed to fixate on some particular ideas. For example, in this particular case, teams fixated on using all the materials provided to them. They wanted to use all the materials without thinking about other possible solutions that could serve the purpose better.

Ignore uncertainty

This strategy includes actions like dismissing or paying no attention to the introduced uncertainty and moving forward without addressing them. For example, consider the following episode:

A1: Our robot will clean everything.

A2: Should we use eraser dust? Won't it be difficult to clean it? It kind of…sticks to the floor.

A1: This is not important right now; we will be able to do it.

Here, learner A2 of group A expressed the uncertainty about whether their design will be able to clean the eraser dust (one of the trash material). Learner A1 completely ignored this uncertainty by calling it unimportant. The uncertainty raised by the team member was regarding the constraints specified in the design problem. If this uncertainty had been addressed, the team may have realized that cleaning the eraser dust was not easy with the provided materials and this might have helped the team to further refine the design.

Delay action

This strategy includes delaying action, decision, or evaluation. For example, consider the following episode:

B1: Pass me the cost calculation sheet. I am worried that our robot will turn out a due to cost.

B2: Wait, let us first complete and then calculate, we have to make so many changes.

B3: Yeah, lets first program it and test it that is more important.

Here, in Group B, B1 expressed her concerns regarding the cost of the robot. She wanted to calculate the cost to ensure that their budget was in control but the other two members asked her to do it later thereby delaying the action on it.

Observe and replicate

It means observing the actions of other team members, other groups or an authority figure. Only group B used this strategy. For example, consider the following episode:

B1: See, they have used the cage [structure to hold the EV3 brick].

B2: Yeah I think we should also just do it and start testing, we have no time left.

We observed that when group B was struggling with the uncertainty about how and where to place the EV3 brick for a long time and failed to resolve it after many attempts; they went off to see the design of the other team and modified their design.

Ask and apply

This strategy refers to asking for a solution from a teammate or an authority figure and then applying it directly. For example, consider the following episode:

A1: So, if you have to clean the dry dust, do we have to take it or we have to just move it aside?

Mentor: See that is your wish, anything works.

A1: So, even with the sponge we can just move it like this [Shows dragging action].

There were many instances like this one for group A where the team members preferred approaching an authority figure like a mentor instead of discussing it among themselves. However, for group B, there was a lot of discussion happening among the teammates and there were only a few instances where they preferred asking for a solution directly.

Discussion

Students collaboratively managed the uncertainties using the management strategies mentioned in the above section. It was observed that students faced some issues while using these strategies which led to ineffective uncertainty management. For example, in the case of analysis and brainstorming, the dominance of certain team members led to unequal participation. A potential solution to this problem is to follow a structured way of collaborative turn taking or use of collaborative dialogue or negotiation tools (Jeong & Hmelo-Silver, 2016). Similarly, sketches played an important role in guiding discussions during analysis and brainstorming, but superficial sketches weakened their analysis as they missed important aspects to be analyzed. Majorly, these sketches lacked specifications like dimensions, size, materials, etc. and were incompletely labeled. Using collaborative and discussion-led sketching tools with reflective prompts can help in improving the quality of analysis. In the case of argumentation, it was observed that students' actions were not backed with appropriate reasoning. Using argumentation construction tools for helping students construct sound arguments might be a solution to this problem. Also, while brainstorming, teams got fixated on certain ideas which restricted them from further exploration. Engineering design tools like 6-3-5 Method, C-sketch method and the Gallery method (Dym et al., 2009) can help the teams expand the solution space while brainstorming.

Further detailed studies need to be conducted to understand different issues involved in the process of collaborative uncertainty management. Technological affordances, like the ones discussed above, can then be utilized to solve these issues and help learners manage uncertainties effectively.

Conclusion

The preliminary results presented in this paper help us understand how middle school students manage uncertainty while solving an engineering design challenge collaboratively. Effective scaffolds for helping learners to manage uncertainties collaboratively can only be designed once we understand what problems and issues learners face during the management process. The work done in this paper is, therefore, an important step in gaining insights about what form and features can a computer-supported collaborative learning environment possess to ensure that learners are able to develop the skill of managing uncertainties effectively.

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