Ogata, H. et al. (Eds.) (2015). Proceedings of the 23rd International Conference on Computers in Education. China: Asia-Pacific Society for Computers in Education

A Game to Improve Hypothetico-Deductive Reasoning Skill in undergraduates

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Abstract: In this paper we describe sequence of steps taken during the different phases of design based research (DBR) while developing murder mystery game intended to teach hypothetico-deductive reasoning (HDR). Murder mystery game is a collection of sequential activities which aims at solving mystery. The underlying principle behind different activities is to teach HDR. In the first phase of DBR students were assessed through questions in three different context i.e. murder mystery, determining genotype of a pea plant and crashing Firefox. Difficulties faced by students during HDR were identified by analysis of results of first phase and inputs from literature. This fed into next phase of designing an intervention. In the next phase students' interacted with the intervention. Feedback from students through analysis of survey after interaction with intervention gives an insight into a number of user interface issues which is to be addressed in the next cycle of DBR.

Keywords: Hypothetico-deductive reasoning, design based research, murder mystery

1. Introduction

Hypothetico-deductive reasoning (HDR) is important for understanding the underlying reason behind any phenomenon. It is shown to be required in understanding of various phenomena related to science and technology (Lawson, 2000; Bao, 2009). This skill is important for designing experiments in a scientific research study. Even 21st century skills aim at developing HDR in the context of problem-solving abilities. Researchers have pointed out various difficulties faced by students during HDR. Various teaching strategies (project based learning and inquiry based learning) and technology-enabled learning (TEL) environment (WISE) (Slotta, 2002) have focused on helping the students to overcome the difficulties and improving this reasoning skill.

Many studies focus on teaching this reasoning skill to school children and few studies focus on teaching HDR to undergraduates. The affordances that a game can provide in teaching this to undergraduates are also not completely explored. We analyzed the literature related to the difficulties in teaching-learning of HDR and did a pen and paper study with students. On the basis of these we identified the features to be included in a TEL environment that would help students in overcoming the difficulties. We intend to evaluate our design of the game with respect to the following specific research questions:

1. What are the difficulties faced by undergraduate students while doing HDR?
2. What are the characteristics of web based browser game which focuses on improvement of HDR skill?

We performed a pilot study with the developed game and identified the technical and user interface (UI) changes to be made in the game. We consider this as the first cycle of DBR process.

2. Related Work

2.1 Hypothetico-deductive reasoning (HDR)

HDR is a series of reasoning steps followed during scientific inquiry (Lawson, 2004). These steps are formation of testable hypotheses, designing a feasible experiment to test this hypothesis, comparison of results (predicted and observed) and forming conclusion. Without sufficient chunking of the information, constructing arguments in working memory and deriving conclusions is difficult (Lawson, 2003). In order to help students to overcome these difficulties different teaching strategies and TEL environments have been developed. Many TEL environments focus on improvement of scientific

reasoning skill in general but don't focus on HDR explicitly. Researchers have pointed out various difficulties faced by students during HDR. Some of them are difficulty in hypothesis formation, predicting result, drawing conclusions and connecting back to existing theory (De Jong and Van Jollingen, 1998). So suggestions have been made for the improvement and transfer of this skill (Adey and Shayer, 1994; Chen and Klahr, 1999).

2.2 Existing environments for teaching-learning of HDR

Various teaching-learning strategies like project based learning and inquiry learning focus on developing scientific reasoning which can be in the form of blended learning environment. Also TEL environments like WISE and Inquiry island (Slotta, 2002; Eslinger, 2008) focus on development of scientific reasoning. Within different steps of these environments, scientific reasoning pattern is required but they are not made explicit. Mostly these TEL environments are created in the context where subject knowledge is more important than reasoning pattern. Another example of TEL environment is Geniverse, which is a web based software developed by concord consortium to teach concepts of genetics to high school biology students. It improves scientific reasoning in a game like environment.

2.3 Game-based learning of HDR

At present this reasoning skill is taught by various classroom teaching strategies and different TEL environments. One of them is through computer supported learning environment which has been developed to promote effectiveness in learning among students (Li and Lim, 2008). Also educational games have been shown to be effective in increasing learning motivation and problem-solving skills among students (Moreno-Ger, Burgos, Martínez-Ortiz, Sierra, and Fernandez-Manjon, 2008).These games can provide situated meaningful learning environment along with gaming activity(Hwang, Sung, Hung, Huang, and Tsai, 2012).Both authenticity and learning by doing can affect problem solving abilities among students (Kiili,2007). An interactive educational game is found to be effective in increasing students' motivation (Inal and Cagiltay, 2007).

2.4 Design considerations of TEL environments for teaching-learning of HDR

Many studies talk about the features to be included in the TEL environments or games which aim to reduce the difficulty of carrying out HDR reasoning. In order to help students to overcome the difficulty of tracking everything in working memory, some support to organize evidences and claims, for example an editable notebook should be present (Furberg, 2010). Researchers have argued that recognition of patterns of argument is needed by the students (Lawson, 2004) and scaffolding in the form of explicit prompts will help students to structure their argument. It is shown that students can be guided by features like text accompanied with illustrations and multiple choice selections (Furberg, 2010).

By analyzing the difficulties of learning HDR and the affordances of technology which will help students in dealing with the difficulties, we have designed a web browser based single player game. Since this reasoning skill is required across the domain, we focus on creating an educational game which aims at developing this skill among students. The game is in the form of a murder mystery which is then transferred to the context of biology and computer science. Any student can play this murder mystery game despite being from different educational background. We have adopted DBR approach to design this game.

3. Methodology

DBR is a methodology used to develop theories not just about teaching-learning process but also about the design of the means to support that process (Cobb, diSessa 2003). We have used DBR methodology according to the steps proposed by Reeves (Reeves, 2006). It consists of steps like analysis of practical problem by researchers and practitioners, development of solutions with a theoretical framework, evaluation and testing of solutions, documentation and reflection to produce "design principle" and finally refinement of problems, solutions and methods by revisiting individual steps. Figure 1 shows our adapted version of DBR methodology.

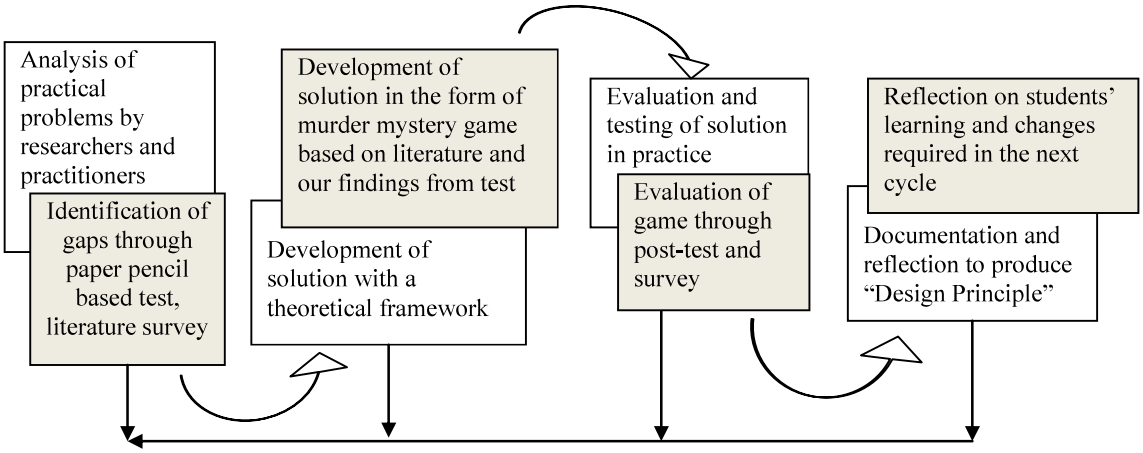

Figure 1: Steps in DBR Methodology (adapted from Reeves, 2006)

3.1 Problem analysis

In order to get a first-hand experience of what the students are able to do without any intervention, we did a study on pen and paper with 29 students in three phases.

Phase 1: The students were given questions related to three domains: a) General: Murder Mystery, b) Technical: Troubleshooting a browser (Crashing Firefox) and c) Biology: Determine the genotypes of plants after crossing. They were asked to find out the answers and support their findings with data.

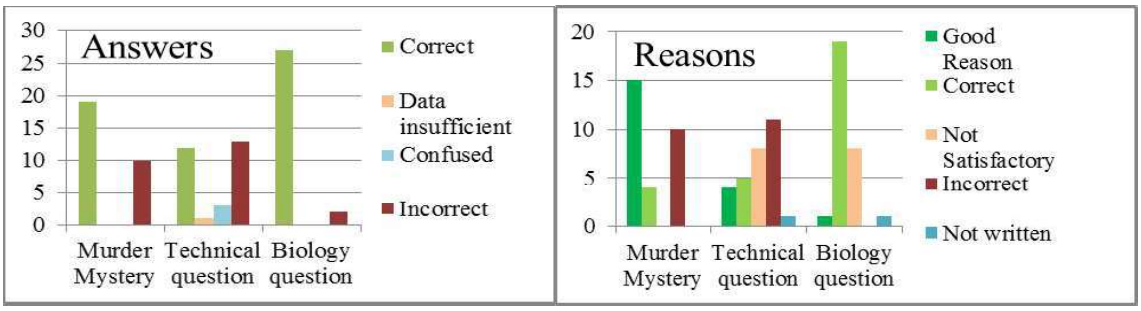

Fig 2: Students responses in phase 1 of problem analysis

Rubrics used for this evaluation is given below:

- Good reason: Provided all the required evidences and correct logical argument
- Correct: Provided all the evidences but no logical argument OR Logical argument but some evidences missing
- Not satisfactory: Some evidences missing and logical argument missing
- Incorrect: No relevant evidences and logical arguments

Analysis of students' responses in Fig 2 shows that most of the students are successful in answering murder mystery with good reasons. In case of technical question, half of them were unable to answer the question correctly. But most of them couldn't give good reasons for questions related to general computer usage and biology. In some of the answers the students seems confused.

Phase 2: In the next phase, they were given a list of hypotheses and facts related to technical and biology question. They had to distinguish between hypotheses and facts. From the second phase, we found that, while solving the technical question, none of the students were able to distinguish between all hypotheses from the facts in technical question - 14 of them identified 3 out of 4 hypotheses and 13 of them identified 2 hypotheses. Their responses in genotype problem too were similar where only 2 out of 29 were able to distinguish all the 6 hypotheses from facts. The other 27 students could identify 3 out of 6 hypotheses. However, 22 out of 29 students identified the facts correctly in technical question and only 5 out of 29 students identified the facts correctly in the genotype question.

Phase 3: In the third phase, they were given the following template:

Because _____ and _____ we can conclude that the murderer is _____.

Because _____ and _____ we can conclude that the Firefox was crashing.
Because _____ and _____we can conclude that the genotype of pea plant is _____.
This was meant to act as a prompt in order to provide answers with reasons or evidences. We analyzed the answer sheets and got the following result shown in Fig 3.

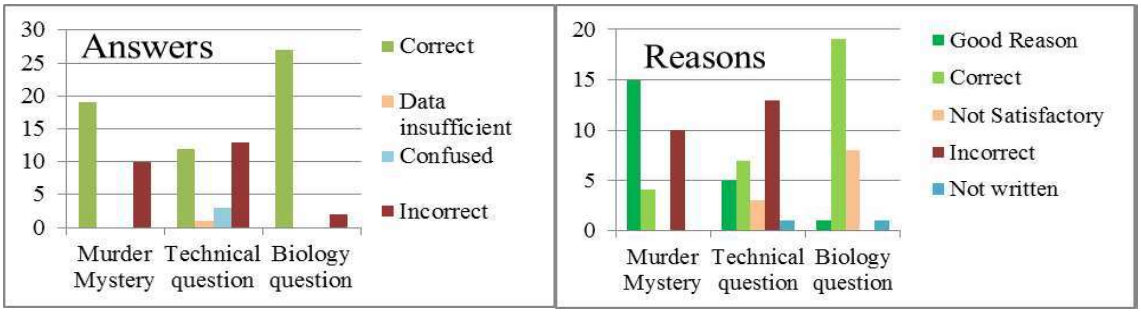

Fig 3: Students responses in phase 3 of problem analysis

Here we observe that few students, who gave 'not satisfactory' reasons in first phase for the technical question, gave correct/good reason in third phase. However, giving the template didn't seem to help much in case of students who gave incorrect reasons in the first phase. In murder mystery and biology domain, the reasons of the students didn't change after giving the template. By analyzing at these results and related literature, we included some features in the game. These are given in Table 1.

3.2 Design and development of the game

This is a web browser based game. The initial screen explains what are hypothesis, prediction, observation and conclusion by giving an example. Then in the next screen the player is given the role of a detective under training. The detective has to go to the murder scene and help an officer with the investigation. Accordingly, we have four steps in the game:

1. Investigation: In this step, the detective interrogates everyone related to the murder say, the victim's employee. The detective also tries to get more information from the investigating officer present in the scene. The player has to click on the pictures of each character to listen to their story. This is assumed to reduce the cognitive load on part of the students because there is an inherent chunking going on. The information obtained by the detective will be automatically stored in a notebook as and when the detective listens to each 'character' in the scene. This notebook can be used in subsequent steps when the detective needs this information.

2. Look for evidence: After collecting information from characters in the investigation screen, the detective moves ahead to look for evidences. For example the detective has to click on a coffee mug to check if it contains anybody's fingerprint. Images of possible evidences are shown and the player has to decide and select the important evidences within a given number of chances to get points.

3. Synthesize: After listening to all the versions of the story and finding out the required evidences, the detective comes to his desk with a set of hypotheses and facts. The next job is to sort these out: The player has to distinguish between facts and hypotheses. A link is given to the initial screen so that they can refer to the definitions of hypotheses etc. Now with all the hypotheses in front of the detective, he/she has to find the ones which are supported by data i.e., he/she have to find which of the hypotheses can be true. Initially, if the detective clicks on a fact, then he/she will get a response that it is a fact. When the detective clicks on a hypothesis, he/she is trained by showing what can be the prediction and observation and conclusion for that hypothesis. This scaffolding is removed in later stages of the game.

4. Conclude: In the next screen the detective has to predict what would happen if this hypothesis is true and then give the required observations to check if the prediction is true or not. Then conclude whether the hypothesis in consideration is accepted or rejected. There are explicit prompts at this stage which asks the detective to enter predictions and observations needed to test the hypothesis considered. This was added to familiarize students with the argument pattern. After the detective has considered all the hypotheses and analyzed which ones are supported by the available evidences, he/she has to conclude who is the murderer.

Difficulties faced by the students	Evidences for the difficulties		Features included in the game to help students overcome the difficulties
	Literature	Our findings from problem analysis	
Students find it hard to parse large amount of text at once	Lawson, 2003	Students said that reading long text is frustrating and demotivating.	Characters - Dividing the complete text as dialogues by different characters forms the first level of chunking.
			Each mystery is divided into different steps of investigation.
Students are not able to refer to different parts of the text when needed	Furberg, 2010		Notebook - no need to go back and forth, reduces memory load
Students find it hard to connect related parts from large amount of text at once.	Lawson, 2003	Students failed to support their claims with correct evidences.	Evidences- Evidences are included as a separate step where students already know the context and are searching only for the evidences
Students find it difficult to present their argument logically	Lawson, 2000; Lawson, 2004	Many students found the correct answer but struggled to support it with correct argumentation	Scaffolding in the form of how to write prediction and observation for a hypothesis
			Explicit prompts for writing predictions, observations and conclusions
Students find it less motivating while reading only text	Lawson, 2003		Points - motivating gaming element

Table 1: Design considerations for the game

Here the player has to fill the following template and then conclude:
Because _____ and _____ we can conclude that the murderer is _____.
The blanks are in the form of a drop down box where the players have to select a hypothesis supported by evidence and then type in the prediction and observation required to test that hypothesis.

3.3 Evaluation

After the intervention students were given a post-test consisting of three problems related to murder mystery, problem related to genotype identification and computer science in the same sequence and format as in pre-test, except that post-test was online. They had to write prediction, observation and conclusion explicitly within a box which pop up when they select any hypothesis. After attempting the questions they had to fill a feedback form which included two open ended questions. Questions in the feedback form were about features of tool which was useful and challenging. Then some of the students were interviewed in a focus interview regarding usefulness of the tool.

Answers of three questions was analyzed and compared with the rubric created. Feedback of students was analyzed. 11 out of 29 students were able to answer all three questions after their interaction with intervention. Most of the students were not specific in writing prediction and observation. Remaining students were not able to solve murder mystery. 8 out of 29 students filled the feedback form.

3.4 Reflections

Based on participants' feedback and their performance in post-test, we inferred some changes to be made in the next cycle of DBR. We observed that some changes are needed as mentioned in Table 2.

4. Conclusion

Considering that hypothetico-deductive reasoning (HDR) is important even in higher education and lifelong education, we designed and developed a game based on solving murder mysteries to teach HDR. Addition of gaming elements have helped in increasing the motivation of the students but there are many changes required to the game as observed from the first cycle of a design based research

(DBR) study. We propose to implement these changes in the second cycle of DBR and evaluate the effectiveness of the game design for teaching-learning of HDR.

Inferences (learning and UI issue)	Changes in next cycle
Boring to read just text	Audio and video format to be included
Confusion in hypothesis and prediction	More scaffolding related to hypotheses testing by prediction and observation
Clicked next without writing prediction and observation	Writing prediction and observation will be made mandatory
Same action (Click on image) to know more about an evidence and to select it as the important evidence	Separate actions for these two tasks
From experts' suggestions	Editable notebook

Table 2: Inferences and changes needed

Acknowledgements

We would like to thank Prof. Sahana Murthy and Prof. Ashok Basawapatna, IDP – ET, IIT – Bombay for evaluating and guiding our game design and research process. We thank Prof. Deepti Reddy, SIES-GST, Mumbai for helping us with the pilot study.

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