Assessment of visualization-rich learning environments and virtual science fairs

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Abstract

Students reading complex and difficult expository texts often have problems with the cognitively demanding processes of text comprehension. According to the cognitive theory of multimedia learning, the student, integrating the pictorial and verbal representation with prior knowledge. The goal of the study was to develop and validate an assessment tool for students' projects based on visual explanations and representations. Research population included 8th grade students in Leverkusen, Germany. We have employed project-based learning (PBL), visualization-rich learning environments and virtual science fairs, in which students inquire authentic problems in science and engineering. The research method included analysis of visualization items in projects carried out by students. The main sources for students' learning outcomes were their own written reports, such as texts, visualizations, reflections, and the context of the projects or science fairs' posters they designed. These learning outcomes can help STEM teachers to explain and understand students´ scientific reasoning, and gain deeper insight into their learning processes. The findings of this research establish reliability and validity of our visualization assessment tool, which can be used to assess visualization items of science projects done by students.

Keywords - *Visualization, Assessment, Project based-learning*

INTRODUCTION

The Cognitive Theory of Multimedia Learning

Ausubel, Novak, and Hanesian (1978) claimed that humans have a genetic potential for representational learning, which is usually expressed by the end of the first year of life, when children acquire the insight that it is possible to use symbols. When a particular new proposition of representational equivalence is presented, the child is able to relate it to the already established and more generalized version of the same proposition in his or her cognitive structure. Mayer and Moreno (2003) presented the cognitive theory of multimedia learning, which is based on three cognitive principles of learning: (1) people use two channels in learning—the visual-pictorial channel and the auditory-verbal channel; (2) the channels can become overloaded when a lot of spoken words and pictures are presented; (3) meaningful learning occurs when learners engage in active processing within the channels, including selecting relevant words and pictures, organizing them into coherent pictorial and verbal models, and integrating them with each other while incorporating prior knowledge (Mayer, 2002; 2003). The cognitive theory of multimedia specified five cognitive processes in multimedia learning (see Figure 1): (1) selecting relevant words from specific narration or report, (2) selecting relevant images, (3) organizing the selection words into coherent verbal representation, (4) organizing the selection images into a coherent pictorial representation; and (5) integrating the pictorial and verbal representations with prior knowledge.

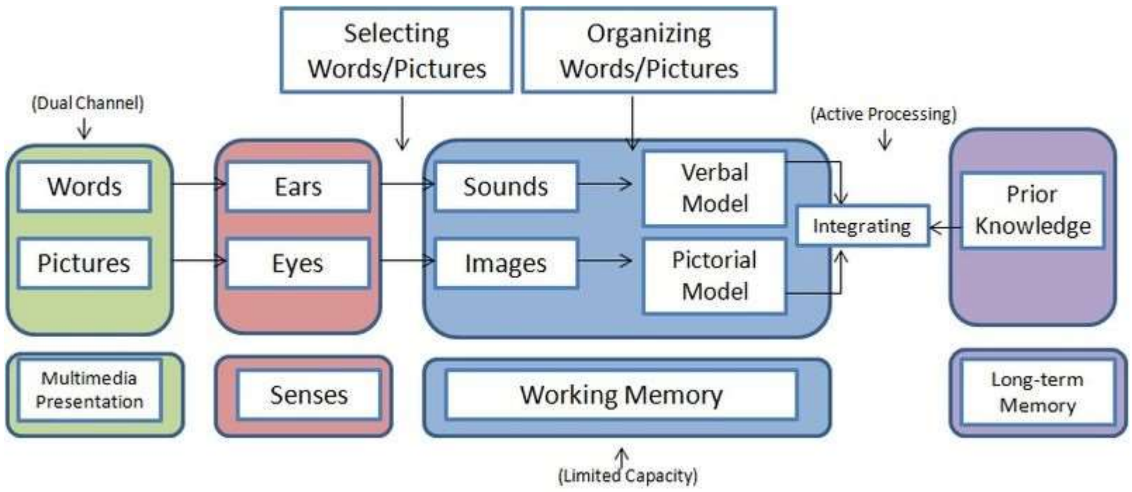


Figure 1: The cognitive theory of multimedia (Mayer & Moreno, 2003)

Vision-based Learning

Vision-based learning involves exposure to richly illustrated texts, multimedia, visual computer interfaces, and hands-on activities, in which students observe, form mental images, and analyze graphs and visualizations of scientific phenomena. "Visible thinking" involves making explicit or concrete the structure of knowledge or the mental models learners and experts use (Jacobson, 2004; Dori & Sasson, 2008). Vision and imagery are different yet complementary concepts. Vision is the process of using the eyes to identify, locate, and think about objects, processes, and systems. Imagery is concerned with the formation, inspection, transformation, and retention of images in one's mind in the absence of a visual stimulus (Mathewson, 1999; Dori & Sasson, 2008).

Students reading complex and difficult expository texts often have problems with the cognitively highly demanding processes of text comprehension (Kintsch & van Dijk, 1978; Schnotz, 1994; 2003). Thus, visualizations can be provided by simply adding them to a text. Accordingly, several studies showed the benefits of multimedia learning on text comprehension and yielded some guidelines on how to design beneficial multimedia instructional messages (e.g., Carney & Levin, 2002; Mayer, 2001). On the other hand, based on models of self-regulated learning (e.g., Boekaerts, 1997; 1999; Weinstein & Mayer, 1986; Zimmerman, 2001), visualizations can also be generated by the students themselves via the "learner-generated drawing strategy" (e.g., Alesandrini, 1984; van Meter & Garner, 2005). Researches on learner-generated visualizations, however, have produced somewhat inconsistent empirical findings: Some studies showed positive effects of learner-generated visualizations on text comprehension, whereas others did not. Thus, so far research on learner-generated visualizations has not provided instructional design guidelines.

Project-Based Learning

Project-based learning (PBL) is a teaching method in which student or a pair of students receives an authentic problem that does not have a single proper solution (Barron, Schwartz, Vye, Moore, Petrosino, Zech, & Bransford, 1998). During learning, the student goes through an exploration process, which involves analyzing and searching for possible solutions, choosing a solution, claiming and explaining his/her choice and creating a demo or a real product (Dori & Silva, 2010; Hsieh & Knight, 2008). Therefore, PBL increases the responsibility for active commitment of the student to his/her learning or peers (Albanese & Mitchell, 1993; Wengrowicz, Dori & Dori, 2012). PBL enhances higher order thinking skills, including data analysis, problem solving, decision-making, and value judgment (Barak & Dori, 2005). The PBL approach represents a shift from the traditional learning into students' learning in a variety of active learning environments and for different age groups (Magid, Tal & Kali, 2011), which can mimic real life settings in companies and industries. Therefore, the teachers and educators may use the PBL approach to prepare students for successful and beneficial integration into society and industry as adults (Dori & Silva, 2010). PBL involves both theoretical and practical aspects, and it potentially conveys to students explicit and meaningful subject matter content from various disciplines (Dori, 2003).

Inquiry

The National Science Education Standards (NRC, 1996) indicated that inquiry is central to students' scientific literacy. Inquiry pertains to both content understanding on one hand, and thinking skills on the other hand. In the content aspect (Lunetta, 1998), students are encouraged to explain their experience and mentally construct concepts (such as mole or energy) and processes (such as acid-based chemical reactions). In the thinking skills aspect, Hofstein and Lunetta (2004) included in inquiry identifying and posing scientific questions, forming hypotheses, designing and conducting investigations, formulating and revising explanations, and defending scientific arguments.

Problem-based Learning vs. Inquiry-based Learning

Inquiry-based learning is a student-centered, active learning approach focused on questioning, critical thinking, and problem solving. Inquiry-based learning activities begin with a question followed by investigating solutions, creating new knowledge as information is gathered and understood, discussing discoveries and experiences, and reflecting on new knowledge. The primary difference between PBL and inquiry-based learning relates to the role of the tutor. In an inquiry-based approach, the tutor is both a facilitator of learning, who expects and encourages higher-order thinking, and provides information. In a PBL approach, the tutor supports the process and expects learners to make their thinking clear, but the tutor does not provide information related to the problem—that is the responsibility of the learners (Savery, 2006).

Science Fair

Science fair is an instance of the PBL method, in which students choose the topic for their projects by themselves, work on their own experiment or science project, and in the end have to present it at school in front of their peers. Science fairs have a long tradition in the USA and in Great Britain. Recently, other countries, such as Germany, have adopted this method. A new type of science fair is the virtual science fair, where e-mentors help and support students online with their science projects (Jonas-Ahrend, 2013).

RESEARCH GAOL AND METHOD

The goal of the study described in this paper was to develop and validate an assessment tool for students' projects based on visual explanations and representations. For this purpose we used the visual items that appear in the 8th grade students' reports, which they wrote as part of the science fair in Leverkusen, Germany.

Research Participants and Setup

The research was conducted within the framework of virtual science fair courses at the 8th grade at Werner-Heisenberg Gymnasium in Leverkusen/Germany. The course objective was to provide an inquiry product, the inquiry work was done by pairs following a project-based learning approach. The final products were presented in a science fair. Each product was summarized by a report that was analyzed in this research. The research was done on a sample of nine reports comprising 27 visualization items. We developed and validated a visualization item assessment scale in order to evaluate the students' understanding level as reflected in the visual items they had developed.

Research tool

The visualization assessment tool was developed by analyzing 27 visualization items from a descriptive-interpretive perspective, relying on previous work (Saar, 2007) and the cognitive theory of multimedia learning (Mayer, 2002). Saar (2007) proposed criteria for encoding students' responses to a visual representation of chemical understanding, which included presence of a picture or graphic, relevance to the subject, number of items, and number of chemistry understanding levels. Inspired by this work, we created a rubric (see Table 1) and its content was validated by three researchers who are experts in science education and science project assessing.

1. **Visualization type**: the visualization types were characterized into table, graph, picture, schema, flow chart, drawing, and other. This variable serves as a classification variable only, and there is no extra grading based on the type of the item.
2. Item title: examining whether there was a title or an explanation attached to the visual item and if so, what was its level of its precision and clarity
3. Relevance to the main text: examining whether the visual item is relevant to the main text of the subject matter in the place it was inserted, and if so, whether it is slightly, moderately, or highly relevant.
4. Contribution to the main text: examining whether the item contributes to understanding the text, and if so, whether this contribution is small, medium, or high.
5. Extent of coverage: examining the extent to which the visual item contains the information needed in the context where it appears and is adapted to what is described in the text.
6. Appearance: examining the extent to which the item looks attractive in terms of aesthetics, size, brightness, color selection, etc.
7. Science understanding levels: examining what levels of understanding are reflected by the visual item. There are four understanding levels: (a) the symbol level that contains formulae, equations, and graphs; (b) the macroscopic level that includes the observable/tangible phenomena; (c) the microscopic level which give explanations at the particle level (Gabel & Bunce, 1994; Johnstone, 1991; Treagust, Chittleborough, & Mamiala, 2003) and (d) the process level, which deals with the way substances react with each other (Dori & Hameiri, 2003; Dori & Sasson, 2008). The process level can be explained in terms of one or more of the first three levels.
8. Societal added value: examine whether the visual item reflects added societal or affective value, such as team collaboration, active work, the expression of emotions.

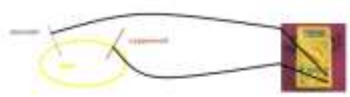
Table 1. Visualization item assessment- rubric

Visualization type	**Item title**	**Relevance to the main text**	**Contribution to the main text**	**Extent of coverage**	**Appearance**	**Science understanding levels**	**Societal added value**
	no title (0)						
table	no clarity, no precision (0)	not relevant (0)	no contribution (0)	limited (1)	slightly attractive (1)	macro (1)	no added value (0)
graph	precision but no clarity (1)	slightly relevant (1)	minor contribution (1)	moderate (2)	moderately attractive (2)	micro (1)	added value (1)
picture	clarity but no precision (1)	highly relevant (2)	significant contribution (2)	full (3)	highly attractive (3)	Symbol (1)	
schema	clear & precise (2)					process (2)	
flow chart						2 levels (2)	
drawing						3 or 4 levels (3)	
other							

The reliability of the students' visualization items assessment tool was tested by three judges who are experts in science education. They were asked to evaluate several identical visualization items based on the rubric, which we presented in Table 1. The level of their agreement is presented in the findings section.
Table 2 presents an example of evaluating each visualization type based on the categories of the visualization items and its rubric.

Table 2: An example of evaluating each visualization type based on the categories of the visualization items in the rubric in Table 1.

Item	**Visuali-zation type**	**Item title**	**Relevance to the main text**	**Contri-bution to the main text**	**Extent of coverage**	**Appearance**	**Science under-standing levels**	**Societal adde**
 Pic. 2: Sarah drawing Lake Oulu water	picture	clear & precise (2)	Significant (2) The procedure is expressed	Significant (2) Give visualization for the procedure	Full (3) Covers the process of collecting water	Significant (3) Good size and visibility,	Macro & process (2)	active work, team work (N was the photographer) (1)
	picture	not clear, not precise (0) There is no title (we can see that this is the McDonald	not relevant (0) Present at the end of the report, no connection for any	No contri-bution (0) No mentions which day it's from.	Tight (1) Cover only the McDonald brand, no mention, which part of the process,	Moderate (2) Good size and visibility, But not all the parts can be seen	Macro (1)	No added valu (0)

		burger from the box). No mention which day it's from.	part.		it's from.			
Connect them with the cables with the voltmeter 	Schema	No sub title (0)	Significant (2) relevant	Significant contribution (2)	Full (3)	Significant (3)	Macro & Process (2)	No added value (0)
Bread type / **Vote** **Bio - Bread** 4 **bread from the baker** 6 **Bread from the discounter** 20	Table	No sub title (0)	Slight contribution (1) relevant there is a graph, no need table	Slight contribution (1) there is no a graph, but a table	Full (3)	Moderate (2)	Macro (1)	No added value (0)
	Graph	No sub title (0)	Significant (2) relevant	Significant contribution (2)	Full (3)	Significant (3)	Macro (1)	No added value (0)

Findings and Analysis

Correlation tests, which point the level of agreement between judges in each category, are presented in Table 3. These findings indicate that five of the seven categories are significantly reliable. We summarized each item and each judgments separately for the grades of the five reliable categories. The level of agreement between judges for the summarized total grade ranged from .82 to .92 and were all significant (p<.01).

Table 3: Agreement range between judges of visualization items vs. category of the assessment tool

Category	Min	max
Item title	.80*	.95**
Relevance to the main text	.81*	1**
Contribution to the main text	.73*	.92**
Extent of coverage	.68*	.87**
Appearance	$.30^{ns}$	.90**
Science understanding levels	.68*	1**
Societal added value	$.51^{ns}$	1**

** p<.0.01; * p<.0.05; ns –no significant

Two of the seven categories, appearance and societal added value, were not clear enough and were excluded from the rubric at least for the time being, since they were unstable and sensitive to subjective judgment and personal style.

DISCUSSION AND CONCLUSIONS

We have developed and validated a new tool for assessing visualization items produced by students carried out as part of team projects. We described the motivation and underlying ideas behind developing the tool. We set up evaluation categories and organized them into a rubric with a grade level for each category. We tested the content validity of the categories of our visualization assessment tool by three researchers. We then tested the reliability of the tool by calculating the level of agreement between judges, who were asked to grade exemplary visualization items. In our future research, we will continue to test the validity of this tool by examining the correlation between textual assessment and visual assessment, and refining the categories, possibly adding a clearer version of the two categories that had to be excluded. Our study and findings contribute to the theory and practice of both assessment and project-based learning. They provide a reliable tool for assessing scientific works of students who express themselves by visual means. This tool can be used not only by researchers but also by teachers who need to evaluate students' understanding by assessing the visualization items that students had developed as part of their projects.

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