Prompting and Language in Metacognitive Instructional Design for Digital Science Learning: Implications for Teaching in Medical Schools

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ABSTRACT

In science education at all levels, including in medical school, the use of digital technology-based learning has become ubiquitous. While digital learning tools hold much promise for science education, the question arises as to whether or not such technology can serve as an adequate surrogate for the teacher-student interactions that theorists like Lev Vygotsky (1978) underscored as being critical to learning. In response to such concerns, designers of digital curricula often utilize scaffolds to help students as they learn from such programs. Using a simulation designed to teach students about the concept of diffusion as an example, I examine the effect of including prompting language in the learning sequence of the simulation. The use of prompting language in digital curriculum appears to be successful because it elicits science students to reflect and metacognise about their learning, lending support to Vygotsky's (1978) ideas of teaching and learning involving outer and inner dialog. However, findings from think aloud data continue to underscore the importance of human linguistic exchange as a preferable learning paradigm.

Keywords: metacognition, digital learning, science education, reflection

1. INTRODUCTION

Despite the evidence attesting the importance of metacognitive development, science classrooms at all levels are often characterized by a lack of metacognition instruction embedded in educational activities and curriculum. Additionally, the educational research community cannot amply provide rationale to explain why implementing such instruction is critical. Providing science teachers with the strategies to encourage metacognition growth in their students and the programs, resources, and curricula to support these efforts will likely encourage the extent to which metacognition is discussed within the academic context. While it is clear that metacognition contributes favorably to science and chemistry learning, many questions still remain around how to best incorporate metacognition instruction into science education, including: What components of metacognitive instructional design are most positively associated with science learning outcomes, particularly in the context of multimedia learning? How and why does the language of prompting elicit students to be reflective and increase metacognitive thinking? Does prompting language embedded within multimedia science curriculum serve as a substitute for a mentor in the Vygotskian notion of the Zone of Proximal Development? To answer these questions, continued development and testing of resources based on the
research evidence around metacognition instruction in science education are important priorities for researchers and practitioners committed to promoting metacognitive growth in students and provide a rationale for this study which seeks to make a deeper analysis of prompting and metacognitive thinking.

2. METHODS

The original and most common method to determine metacognitive thinking is direct verbal questioning, often while subjects participate in an activity (Flavell, 1978). In recent years, however, researchers have popularized the use of self-report surveys due to ease of scoring and analysis. Self-report questionnaires have demonstrated to be good predictors of students’ standard achievement test scores and results correlate well with achievement levels (Pintrich et al., 1993; Zimmerman and Martinez-Pons, 1986). Although self-report surveys can be problematic for several reasons, including positive response biases and underreporting of thinking processes (Turner, 1995), they can also be insightful providing a sense of where learners are situated with respect to the metacognitive skills they manifest. However, for the purposes of this study, they do not fully capture the dynamic nature of metacognitive thinking. Thus, some researchers have lauded the use of a combination of on-line and off-line measures of metacognitive processes, where on-line methodologies capture any activity that occurs during processing, whereas off-line methods capture any activity that happens either before or after processing (Azevedo et al., 2009). The idea behind this approach is the metacognition is an evolving event that is best understood by observing real-time events. It is for this reason that I choose to utilize a diverse tool kit to understand metacognitive thinking in this study and to look for converging evidence. Influenced by the term “thick description” used by Geertz (1973), I adopt an approach to understanding metacognition in science learning that is richly descriptive and contextual.

Research Participants, Setting, and Materials

This study was conducted using students from high school chemistry classes in the New York City public school system. Students from New York City public schools were recruited through the Molecules & Minds project at the Consortium for Research and Evaluation for Advanced Technologies in Education (CREATE) at New York University’s Steinhardt School of Education, Culture and Human Development.

The Molecules & Minds diffusion simulation is a computer sequence that incorporates several elements into a single-stream user sequence, with random assignment to experimental and control conditions (see Figure 2). The experimental condition makes use of problematizing prompts (see Figure 3) such as “What do you REALLY know about how smells travel?” and “You may think you already know the answer. Well, maybe you do and maybe you don’t. Take a careful look at…”

Data Collection and Selection Methods

The majority of the data collection is automated in the Molecules & Minds diffusion simulation sequence. Other data such as questionnaires and surveys were collected offline in the form of paper-based measures. Click and user log data is generated from each user of the Molecules & Minds simulation sequence and is captured and recorded by the CREATE lab servers. The think aloud protocols and interview data is collected by interacting with individual students asking them to relay their thoughts as they work through the simulation. A subset of students were be randomly selected to go through the diffusion simulation while thinking aloud. Think aloud data is audio-recorded as is interview data. In the following section, more information is provided on the data sources informing this study.

Data Sources

This study utilizes a mixed methods (Johnson, Onwuegbuzie & Turner, 2007 ), utilizing both quantitative and qualitative methods, approach to answer questions about the interplay of problematizing prompting, metacognitive thinking and learning science from multimedia simulation. Past research has indicated that the use of metacognitive strategies in students has been complicated to assess because cognitive processes and knowledge are difficult to access and document. The use of different data sources helps to establish a more complete understanding of the interplay between prompting language and metacognition. The data sources used were Pre-test, Post-test Assessment, self-report survey data on the Metacognitive Awareness Inventory (MAI) (Schraw & Dennison, 1994) and Think Aloud data. In the think aloud method protocol (Ericsson & Simon, 1993), participants are prompted to talk aloud during their learning, thinking and problem-solving; these verbalisations are typically analyzed by a coding paradigm (Pressley & Afflerbach, 1995).
3. RESULTS

The current study examined the interaction between prompting scaffolds in a computer-based learning environment and metacognitive learning styles in students of chemistry. Both qualitative and quantitative data were gathered and this chapter presents the statistical outcomes and analysis of the results. The results of the statistical analysis are presented by participant groups: problematizing dataset and think aloud dataset, and, finally a comparison of the two datasets. Scores on the Metacognitive Awareness Inventory (MAI), pre-test and post-test gains, and simlog data are discussed below. This chapter concludes with the summary of the results as related to the research questions.

**Problematizing Dataset**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Frequency</th>
<th>Percent</th>
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<tbody>
<tr>
<td>Metacognitive Score</td>
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</tr>
<tr>
<td></td>
<td>H</td>
<td>51</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>Treatment</td>
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<td>51</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>72</td>
</tr>
<tr>
<td>School</td>
<td>Civic Leadership</td>
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<td></td>
<td>UAI</td>
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<tr>
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</tr>
<tr>
<td>Total</td>
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<td>123</td>
</tr>
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</table>

**Pre-Post Test Gains**

Results show a statistically significant interaction between Metacognitive score and Treatment on Pre-Post Test Gains, F(1, 102) = 7.84, p = 0.006, η = 0.071. Effect size for the interaction is really small (η = 0.071). This indicates that the differences are not that strong for the interaction of Treatment and Metacognitive Scores.
**Problematizing Data versus Think Aloud Data**

The main research question was: What sort of thinking do students engage in when they interact with the simulation under a non-problematizing condition and a problematizing condition? Coding and analysis of a significant portion of the think aloud data did not reveal any patterns or differences between treatment groups or metacognitive score groups and is not included in this discussion.

**Pre-, Post-test Gains**

Figure 1 compares the Mean Pre-Post Test Gains by Metacognitive Score of the Problematizing and Think-aloud datasets. The Problematizing dataset shows higher mean Pre-Post Test Gains for those with Lower Metacognitive Scores whereas the Thinkaloud dataset shows higher mean Pre-Post Test Gains for those with Higher Metacognitive Scores.

![Figure 1: Mean Pre-Post Test Gains by Metacognitive Score of Problematizing and Think Aloud Datasets](image)

**Table 3: An Interaction between treatment and Metacognitive Score with Regard to Pre Post Test Gains**

<table>
<thead>
<tr>
<th>Tests of Between-Subjects Effects&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Dependent Variable: preposttestgain</th>
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<tr>
<td><strong>Source</strong></td>
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<td>Corrected Model</td>
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<tr>
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<td>metacognitivescore</td>
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<tr>
<td>treatment</td>
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<tr>
<td>metacognitivescore * treatment</td>
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<tr>
<td>Total</td>
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</tr>
<tr>
<td>Corrected Total</td>
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</tbody>
</table>

<sup>a</sup>: Phase = Phase 1 – Problematizing, b: R Squared = .158 (Adjusted R Squared = .136), * indicates significance at 0.05 level, ** at 0.01 level

4. DISCUSSION

The current study aimed to explore the interaction between metacognitive thinking and the use of a problematizing prompting scaffold in a computer-based learning environment for students of chemistry. The main questions in this study were whether or not problematizing prompting elicited more metacognitive thinking in students who used a computer program on the phenomenon of diffusion than in students who did not receive the problematizing prompting. The study was quasi-experimental and utilized a pre-post-test design.

Data was collected from a variety of students of chemistry between the years of 2011 and 2015. Students were randomly grouped into control (no problematizing prompting) and experimental (problematizing prompting) conditions. There was also a second additional group of students who underwent the think aloud protocol procedure (Table 2, Table 3).

In the current study, there were three hypotheses. The first hypothesis was that problematizing prompting would lead to greater pre-, post-test gains for students in the experimental condition. The second hypothesis was that the mechanism by which the problematizing prompting would lead to greater pre-, post-test gains was due to eliciting metacognitive thinking in students in the experimental condition. The third hypothesis was that utilizing a think aloud protocol would help to unearth the metacognitive thinking processes that were being elicited by the problematizing prompting.

Both quantitative and qualitative data were collected from the students. The quantitative data consisted of pre-, post-test scores, scores on the Metacognitive Awareness Inventory, and simulation duration and interaction counts. The qualitative data consisted of recordings taken during the think aloud protocols. The following discussions are based on the combination of quantitative and qualitative data collected. While the qualitative (think-aloud) data was originally collected to give insight into metacognitive thinking, the quantitative results from the think aloud group yielded unexpected results of interest and relevance to the metacognitive thinking process in learning and the role of language. In this chapter, I discuss the insights gained into the interaction of problematizing language and metacognitive thinking in a computer-based learning environment. The first discussion will focus on overall findings with utilizing problematizing prompting in students of chemistry while they are learning in a computer-based learning environment.

The second discussion focuses on the interaction between metacognitive thinking as a trait and benefits gained from being exposed to problematizing prompting. The third discussion is the on think aloud group and findings associated with this group. The fourth discussion is on comparisons between the think aloud student group and the non-think aloud student group and the implications of the differences between these groups.

Problematizing Promptings and the Interaction between Problematizing prompting and metacognition

As expected, the students who were in the experimental condition (receiving problematizing prompting) had greater pre-, post-test gains as compared to students who did not receive problematizing prompting as part of their computer-based learning sequence. The problematizing prompting condition consisted of a series of prompts (i.e. “What do you really know about how molecules move?”) that were designed to elicit reflection on students as they navigated the diffusion simulation.

Problematizing versus think aloud

When compared to the non-think aloud group, the students who underwent the think aloud protocol had significantly greater pre-post-test gains, significantly longer simulation duration and significantly greater number of independent simulation interaction counts (Figure 11). It should be noted that it was expected that think aloud students would have significantly longer simulation duration scores because the nature of the protocol is more time-consuming (Figure 12). However, greater pre-post test gains across both the control and experimental groups and the fact that pre-post test gains were significantly higher for the think aloud group versus the non-think aloud group was unexpected. These significant results were unexpected and not even the original target of using the think aloud protocol but give important insight into the interaction of metacognitive thinking, language and learning. These results suggest that the social interaction that is an unavoidable feature of using the think aloud protocol unintentionally helped students be reflective about their learning process, providing them with an edge over the students who went through the diffusion simulation independently. Metacognitively aware students may be selective and strategic about their thinking (Anderson & Krathwohl, 2008) and engaging in the act of a continuous dialog

about thinking could presumably make students more metacognitively aware. Several studies have looked at thinking aloud during learning as a process. Gagne and Smith (1995) mention that “verbalization makes participants stop and think” and Berry and Broadbent (1987) discuss how thinking aloud can help learners focus attention on salient details in learning. Berardi-Coletta et al. (1995) found that verbalization during problem-solving indicated metacognitive thinking, enhancing problem-solving. Since some studies have shown that think-aloud may induce or change thinking in participants, Russo et al., 1989 and Schooler et al., 1993 argue against the think aloud method as a metacognitive assessment tool due to the question of its underlying reactivity and their position may be relevant. While the think aloud method may not be a good metacognitive assessment tool, it may function as a useful metacognitive prompting tool. Prompting methods such as think aloud and reflection prompts appear to be effective instructional techniques, being especially impactful in students who are not spontaneous metacognitive thinkers and for whom self-regulation as governed by internal language does not exist or is not an automated habit (Gredler, 2009). It is known that teacher talk plays a powerful role in modeling and creating a reflective classroom (Bandura, 1986; Zimmerman, 2013). When prompting is used, a learner will, in theory, internalize its language (Bloch, 1993) and this internalization can improve ability to plan, complete and evaluate a task (Menzies & Lane, 2011). In science learning environments, whether computer-based or classroom-based this sort of prompting is a powerful and constructive tool intrinsic to facilitating metacognitive thinking in learners. A fundamental goal of science education is to teach students to become self-directed learners who engage in inquiry and seek out new information. Metacognition may not be a panacea for science education but it is, without a doubt, a key piece in helping students become self-directed. The findings in the present study that indicate that the think-aloud protocol helped students more than the problematizing prompting embedded in the diffusion simulation can also be explained by Vygotsky (1978)’s notions about the importance of the sociocultural perspective of learning. According to Vygotsky, learning with others is essential for development of higher-order thinking processes such as metacognition and, that, there might be no suitable substitute for the unique interactions found in human conversation. Vygotsky (1978) posited that all higher cognitive processes are first born socially in the interpersonal linguistic exchange between two persons and that these processes are later internalized—perhaps technology is not yet at the level of interpersonal linguistic exchange that is needed to adequately facilitate metacognition in learners who need it. In the healthcare industry, where science education is becoming more and more dependent on the use of teaching and learning technology, these are important lessons to bear. It is crucial that medical students and other students in the healthcare field be able to reflect on their learning; relying solely on the interactions of students with digital learning devices may not be the optimal route.

REFERENCES
