Development and Validation of a Behavioral Measure of Metacognitive Processes (BMMP)
Yoo Kyung Chang, Jan L. Plass, & Bruce D. Homer
Consortium for Research and Evaluation of Advanced Technologies in Education
New York University

Presentation Type: Theory & Research

Short Description (75 words or less):
A behavioral measure of metacognitive processes during student’s exploration of a science simulation based on log file data is described. This behavioral measure was found to predict performance on a comprehension test, whereas a self-report measure of self-regulation and a test of prior knowledge did not predict the learning outcome. Results also show that student’s metacognitive control mediated the learning outcome for students with high- but not for those with low prior knowledge.

Abstract (750-1000 words)
Based on the assumption that learning is a generative process involving human cognitive, metacognitive and motivational processes (Wittrock, 1990), the focus of learning is not only on the final outcome (i.e. performance outcome) but also the process of learning (Mayer, 1999). The interactive nature of computer-based learning environments impose challenges to learners by leaving the locus of control mainly in the hands of the learners (Clarebout & Elen, 2004; Hill & Hannafin, 2001; Swaak & de Jong, 2001), whereby learners need to be able to manage how, what and when to use appropriate resources to guide them through effective learning process (Hill & Hannafin, 2001). Further, exploratory learning environments impose added burden on the learners to control their learning process according to the learning tasks, learning contexts and their own cognitive level and proceed through the steps to identify problem, develop hypothesis, explore, observe and analyze provided information (de Jong & van Joolingen, 1998), prompting some researchers to call these environments ineffective (Kirschner, Sweller, & Clark, 2007).

Strategies employed by learners to direct their learning process are thought to determine their learning outcome and are studied as metacognitive processes. Metacognition, i.e., the appropriate use of metacognitive and self-regulatory strategies, has been found to influence the effectiveness of learning as well as the use of resources provided in the learning environment (Aleven & Koedinger, 2000; du Boulay, et al., 1999; Clarebout, et al., 2004; Gräsel, et al., 2001; Hill & Hannafin, 2001; Oliver & Hannfin, 2000).

Although metacognitive engagement during learning is considered an important predictor of learning outcome, measures of metacognitive processes have largely relied on verbal reports such as self-report surveys, interviews or concurrent verbal protocols. While verbal data is often used as a method of assessing cognitive processes in different experimental settings, the validity and accuracy of verbal data is long disputed. Verbal reports based on introspection are often considered useful for discovery or identification of psychological processes rather than as a method of verification, which requires more objective measurement for validation (Lashley, 1923).
The present study
In the present study, conducted as part of a three-year research grant *Molecules & Minds: Optimizing Simulations for Chemistry Education*, funded by the US Department of Education’s Institute of Education Sciences (IES), we explored the use of a behavioral measure of metacognitive process (BMMP) during the exploration of a science simulation that is based on the analysis of log file data collected during simulation exploration. Log analysis is thought to be a method that provides effective means of assessing user behavior in computer-based learning environment (Lawless & Brown, 1997; Leutner & Plass, 1998) as it allows for a non-intrusive observation of learner’s actions that can be used to examine the underlying cognitive processes such as knowledge acquisition strategies, information search strategies, and problem solving processes (Guthrie and Dreher, 1990; Lawless, & Brown, 1997). The BMMP and the self-report measure of metacognitive control were examined to identify a possible mediating role of metacognitive processes on the learning effects of exploratory computer simulation. Prior knowledge, widely researched as a learner characteristic determinant of learning outcome (Dochy, Segers, & Buehl, 1999) and found to positively influence performance (Bloom, 1976; Dochy, 1992; Tobias, 1994), was also examined for its influence on the learning performance.

Method
Eighty-eight students from public high school in New York City participated in the research as they studied *Kinetic Theory of Heat* using an interactive computer simulation. Students’ prior knowledge and learning outcome were assessed using knowledge pre- and post-test administered before and after exploring the simulation, respectively. Self-regulatory strategies (8 items survey from MSLQ) were assessed through a self-report survey administered after the treatment. The BMMP was based on learner’s activity log recorded as they used the simulation. Each log file was analyzed for proportion of meaningful action (i.e. sequential testing and observation of at least two different values for an independent variable affecting the phenomenon of *Kinetic Theory of Heat* represented by the simulation) over total number of interaction with the simulation, and the proportion of variables interacted over total number of independent variables that can be explored through the simulation. The two proportions were added to obtain the BMMP score of metacognitive control for each subject.

Table 1. Correlation of BMMP, self-regulation, prior knowledge, and learning outcomes

<table>
<thead>
<tr>
<th></th>
<th>BMMP</th>
<th>Self-regulation</th>
<th>Prior Knowledge</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metacognitive Score</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-Regulation</td>
<td></td>
<td>-.063</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Prior Knowledge</td>
<td>.195*</td>
<td>.119</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Post-test</td>
<td>.424**</td>
<td>-.150</td>
<td>.184</td>
<td>1</td>
</tr>
</tbody>
</table>
** Results and Discussion**

Results show that self-report survey of self-regulation failed to correlate with the BMMP, learning outcome and prior knowledge (see Table 1), and failed to predict learning outcome as shown by non-significant one-way ANOVA on the learning outcome with self-regulation measure as the predictor, $F(1, 85)=2.517$, $p>.05$. Student’s prior knowledge only correlated with their BMMP score, also failing to predict learning outcome as confirmed by a non-significant one-way ANOVA on the learning outcome with prior knowledge as the independent variable, $F(1, 85)=2.191$, $p>0.05$.

Planned-comparison of the BMMP scores for different levels of prior knowledge confirmed the a priori hypothesis that high prior knowledge students will show higher metacognitive control ($M=1.41$, $SD=.59$) compared to low prior knowledge students ($M=1.18$, $SD=.55$), $F(1, 60)=2.66$, $p=.05$ (one-tailed). Our BMMP was found to predict the learning outcome as analyzed by 2x2 ANOVA (prior knowledge: high vs. low x BMMP score: high vs. low), $F(1, 57)=13.51$, $MSE=35.76$, $p<.001$, partial eta squared $\eta^2_p= .192$, where students with higher metacognitive score showed better learning performance ($M=18.69$, $SD=5.46$) compared to student with low BMMP score ($M=12.16$, $SD=6.8$). However, statistically significant interaction effect between prior knowledge and metacognitive score explained the effect of metacognitive process on the learning outcome, $F(1, 57)=5.68$, $MSE=35.76$, $p<.05$, $\eta^2_p=.091$, where the metacognitive control (BMMP) mediated the learning outcomes only for the students with high prior knowledge.

**Conclusion**

The behavioral measure of learners’ metacognitive processes was found to help better understand and predict learning outcomes in simulations compared to a self-report measure. Further research is needed to develop more robust methods of metacognitive analysis from behavioral data based on a theoretical framework (i.e. Self-Regulated Learning) and under consideration of different tool usage patterns and phases (i.e. exploration of tool, hypothesis testing, confirmation etc). The presentation will discuss this frameworks and approaches derived from them to use behavioral data to assess metacognitive processes, and how it can be applies to measure metacognition in simulations, games, and microworlds.

**References**


