On guided invention activities that support scientific reasoning and domain learning

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Introduction

Invention as Preparation for Learning (IPL) involves asking students to invent methods or solutions to challenging problems, prior and in addition to being taught the canonical solution through tell-and-practice methods (direct instruction followed by opportunities to practice the domain). It has been shown that students who engage in IPL activities perform better on domain-level transfer tasks than students who receive tell-and-practice methods alone (Schwartz & Martin, 2004; Roll, Aleven & Koedinger, 2009). It is unknown, however, through what cognitive processes these learning gains occur.

A study was thus carried out to answer the following research questions:

- How does metacognitive scaffolding, which guides students to noticing the deep features in the data, affect the quality of students’ inventions?
- How does metacognitive scaffolding affect students’ use of unsupported inference strategies, such as self-explanations?

Study Participants

Study conditions were applied to 134 freshmen science students, over half of whom were physics majors, across four sections of a first-year physics lab course at UBC. These students had been previously exposed to invention activities that covered topics such as least-squares residuals and uncertainty propagation.

Method

Students in each section were presented with an identical introduction and then worked through individual worksheets in randomly assigned pairs, with access to a spreadsheet program with which to implement their methods. Domain-level prompts were identical between groups, but two lab sections received “Guided Invention” activities with metacognitive scaffolding as outlined in Table 1. Contrasting cases were provided as in Figure 1 to highlight particular features of the domain in their invented inventions, fewer students in the Unguided Invention condition produced formulae that could accurately predict the rankings of slope uncertainties for each case (i.e. \( \delta_m > \delta_b, \delta_m > \delta_g \) and \( \delta_m < \delta_b \)).

Table 1: Metacognitive scaffolding through domain-independent prompts characterized the Guided Invention (treatment) and Unguided Invention (control) groups.

<table>
<thead>
<tr>
<th>Task definition</th>
<th>Included features</th>
<th>Deep features</th>
<th>Deep features 2</th>
<th>Deep features 3</th>
<th>Other features</th>
<th>Other features (variable)</th>
<th>Other features (magnitude)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan &amp; design</td>
<td>Sample Size</td>
<td></td>
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<tr>
<td>Implementation</td>
<td></td>
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<td>&amp; prediction</td>
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<tr>
<td>data set; Rank all data sets based on the invented methods</td>
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<tr>
<td>Evaluation</td>
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</tbody>
</table>

While most students included unprompted self-explanations with their solutions regardless of condition, students in the Guided Invention condition included more deep-reasoning comments that focused on key features of the data, compared with unguided students (Figure 3, Table 2). Metacognitive prompts, therefore, improve the invention process and exploratory data analysis skills.

Results and Conclusions

Students in the Guided Invention condition were 3 times more likely to include new features (Sample Size) in their invented methods, and also made correct predictions more often (Table 2). While there was no significant difference in technical, mathematical qualities of inventions, fewer students in the Unguided Invention condition produced formulae that could accurately predict the rankings of slope uncertainties for each case (i.e. \( \delta_m > \delta_b, \delta_m > \delta_g \) and \( \delta_m < \delta_b \)).

Table 2: Percentage of students who included each of the three features of the domain in their inventions, and whose inventions resulted in correct rankings of uncertainties in the cases.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Included features</th>
<th>Deep features</th>
<th>Deep features 2</th>
<th>Deep features 3</th>
<th>Other features</th>
<th>Other features (variable)</th>
<th>Other features (magnitude)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unguided Invention</td>
<td>Sample Size</td>
<td>Deep features</td>
<td>Deep features 2</td>
<td>Deep features 3</td>
<td>Other features</td>
<td>Other features (variable)</td>
<td>Other features (magnitude)</td>
</tr>
<tr>
<td>Guided Invention</td>
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</tbody>
</table>

Current Work

We are currently examining the effect of faded metacognitive scaffold across 5 invention activities. In addition, we have implemented these tasks using intelligent tutoring systems. Figure 5 shows the Fuel Consumption activity as presented to students using the “Invention Lab 2.0.”

Scientific reasoning skills will be assessed through several methods:

- Quality of reasoning and methods on invention tasks
- Throughout the term’s invention activities
- On transfer activities
- Performance on evaluation (or debugging) activities
- Recreating data from a previous task

Domain-level knowledge will be assessed through a statistics assessment as developed by the researchers.

Acknowledgements

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References
