Investigating and improving the models of programming concepts held by novice programmers

L. Ma, J. Ferguson, M. Roper & M. Wood

Presented By
David Burlinson
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INTRODUCTION

- Computer programming education is still a major challenge
- ITiCSE working group ("McCracken group") study
  - Low preparedness
  - Poor performance
  - High dropout rates
INTRODUCTION

• Computer programming education is still a major challenge

• Sources of weakness:
  • Problem-solving ability [1]
  • Non-viable mental models of key concepts [2,3]

[1] Barnes, Fincher, & Thompson, 1997
INTRODUCTION

• Computer programming education is still a major challenge

• Addressing the deficiencies:
  • Preliminary study of novice students’ mental models
  • 3 studies using constructivist learning model with cognitive conflict and visualization
  • Evaluation of results
• Mental Models

  • Craik (1943): small-scale models of reality
  • Johnson-Laird (1983): working memory constructs
  • Gentner and Stevens (1983): long-term memory
  • Schwartz & Black (1996): long-term models may influence the working models
BACKGROUND

• Mental Models of novice programmers

  • Bayman and Mayer (1983): models of computer activity for BASIC statements
  
  • Kahney (1983): loop or copy models of recursion
  
  • Gotschi, Sanders, and Galpin (2003): loop or copy models of recursion
  
  • **Dehnadi and Bornat** (2006): mental models for assignment statements
  
  • Caspersen, Bennedsen, and Larsen (2007): could not replicate the previous work
• Difficulties of novice programmers - du Boulay (1989)

1. Orientation - what is programming for
2. Notional Machine - general properties
3. Notation - syntax and semantics
4. Structure - patterns and schemas
5. Pragmatics - specify, develop, test, debug
• Difficulties of novice programmers - du Boulay (1989)

1. Orientation

2. Notional Machine

3. Notation

4. Structure

5. Pragmatics
BACKGROUND

• Constructivism

  • Alternative to objectivism - a single objective truth to transfer to students’ minds

  • Learners actively construct knowledge by combining the experiential world with existing cognitive structures

  • A key strategy - cognitive conflict
    • explicitly challenging pre-existing ideas
    • form appropriate, viable mental models
BACKGROUND

• Cognitive conflict
  • A number of supporting results
    • Baser (2006) - heat and temperature content in physics
    • Demircioglu, Ayas, and Demircioglu (2005) - acids and bases in chemistry
  • Some alternative results
    • Limon (2001) - suggested a range of effects
Investigating the viability of mental models held by novice programmers
MOTIVATING STUDY

• Motivated by Dehnadi & Bornat’s controversial study

• Examining mental models of value and reference assignment in novice Java programmers

• 90 participants
  • from an object-oriented programming course using “objects first” approach
  • studied near the end of the course
  • Questionnaire under examination conditions
MOTIVATING STUDY

• Questionnaire format
  • open-ended questions
    • describe the execution of a small program fragment
    • use text or diagrams
    • designed to reveal mental models
  • multiple choice questions (12)
    • predict the result of a small program fragment
    • predefined answers mapped to mental models
  • examined questions related to value- and reference-based assignments
MOTIVATING STUDY

• Questionnaire results
  • open-ended questions
    • 25 (of 90) - too brief or unclear to categorize
    • 11 - clearly used appropriate mental models
    • 54 - at least one inappropriate model
      • non-viable reference models more common
MOTIVATING STUDY

- Questionnaire results
- MC questions
MOTIVATING STUDY

• Questionnaire results
  • Compared results with course grades
    • appropriate models correlated with good performance
    • inappropriate models correlated with bad performance
  • 1/3 of students held non-viable models of value assignment
  • 5/6 of students held non-viable models of reference assignment
A learning model integrating cognitive conflict strategy and program visualization
Building viable mental models of programming concepts is hard
  • information to confirm or contradict models is not easily available

Visualizations can aid construction of mental models of abstract phenomena, however —
  • most tools are based on objectivist models
  • they don't let students explore their own conceptions
  • students satisfied with their pre-existing concepts tend not to accept new ones
PROPOSED MODEL

• General idea:
  • employ cognitive conflict
  • support construction of viable models using a visualization environment
Proposed teaching model

1. Preliminary stage - investigate pre-existing mental models
2. Cognitive conflict stage - challenge pre-existing models
3. Model construction stage - construct viable models with visualization and animation
4. Application stage - reinforce models with applied problems
PROPOSED MODEL

- Visualization tool:
  - step-by-step execution
  - textual descriptions
STUDY A

• Focus on value assignment

• 60 participants
  • from freshman Java course
  • after value assignment had been taught

• Preliminary pre-test to identify models
• Students with non-viable models (38) sorted into two groups
  • Cognitive conflict and visualization
  • Visualization only
• Post-test to investigate model results
STUDY A

- Results
  - Pre-test identified a number of mental models

<table>
<thead>
<tr>
<th>Model</th>
<th>Description of the model</th>
</tr>
</thead>
<tbody>
<tr>
<td>M2</td>
<td>A Java primitive type value is copied from the result of the evaluated expression on the right of the assignment operator to a variable on the left (appropriate mental model)</td>
</tr>
<tr>
<td>MIncon</td>
<td>Different models are used to answer the collection of questions</td>
</tr>
<tr>
<td>M9</td>
<td>Nothing happens when an assignment statement is executed</td>
</tr>
<tr>
<td>ME</td>
<td>Viewing ‘==’ as a comparison operator</td>
</tr>
<tr>
<td>MUR</td>
<td>A variable cannot be ‘rewritten’, i.e. the variable can be only written once</td>
</tr>
<tr>
<td>M11Ss</td>
<td>Variables swap values when an assignment statement is executed + Ss model</td>
</tr>
<tr>
<td>M2Ss</td>
<td>M2 + Ss</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group</th>
<th>MIncon</th>
<th>M9</th>
<th>ME</th>
<th>MUR</th>
<th>M11Ss</th>
<th>M2Ss</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC+Viz</td>
<td>6</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>Viz</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>14</td>
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<tr>
<td>Total</td>
<td>8</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>28</td>
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</table>
### Study A

#### Model change successfully

<table>
<thead>
<tr>
<th>Group</th>
<th>MIncon → M2/Ss</th>
<th>M9 → M2/Ss</th>
<th>M11Ss → M2/Ss</th>
<th>ME → M2/Ss</th>
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<td>9</td>
</tr>
<tr>
<td>Viz</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>14</td>
</tr>
</tbody>
</table>

#### Model change failed

<table>
<thead>
<tr>
<th>Group</th>
<th>M11s → MIncon</th>
<th>ME → MIncon</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC+Viz</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Viz</td>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

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#### Model change successfully

<table>
<thead>
<tr>
<th>Group</th>
<th>M2Ss → M2</th>
<th>M11Ss → M2</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>CC+Viz</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Viz</td>
<td>3</td>
<td>0</td>
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<td>Total</td>
<td>5</td>
<td>1</td>
<td>6</td>
</tr>
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</table>

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<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>
STUDY A

• Discussion
  • No significant difference between treatments ($p = 0.13$)
  • Visualization tool helped students challenge pre-existing model and develop viable mental models
  • Visualization tool was helpful for assignment, but not so much for execution flow
    • tool might not directly challenge all models of flow
STUDY B

• Focus on reference assignment

• 43 participants
  • from same freshman Java course
  • after reference assignment had been taught

• Preliminary pre-test to identify models
• Students with non-viable models (41) sorted into two groups
  • Cognitive conflict and visualization
  • Visualization only
• Post-test to investigate model results and feedback questionnaire
STUDY B

• Results
  • Participants organized into categories after completing study
    • Category 1: became comfortable with the questions and concepts
    • Category 2: improved understanding of reference
    • Category 3: improved understanding of supporting concepts (but not reference)
    • Category 4: realized their understanding was flawed, but did not change understanding
    • Category 5: did not realize understanding was flawed

<table>
<thead>
<tr>
<th></th>
<th>Category 1</th>
<th>Category 2</th>
<th>Category 3</th>
<th>Category 4</th>
<th>Category 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC+Viz</td>
<td>4</td>
<td>1</td>
<td>9</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Viz</td>
<td>0</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>7</td>
</tr>
</tbody>
</table>
STUDY B

• Discussion

• Significant difference between treatments ($p = 0.0202$)

• It might take more time and practice to construct valid models

• Some participants might be building simplified models at first

• Some see they’re wrong but don’t know why

• Reference is harder, requires more base knowledge

• Tool might not be at students’ level
STUDY C

• Repeat motivation study to evaluate proposed teaching method

• 66 participants
  • from freshman Java course
  • near the end of the course
  • 22 participated in study A
  • 18 participated in study B
  • 14 participated in both

• Exact same test and conditions as motivational study
STUDY C

• Results:
  • 30 of 36 (from study A) used appropriate models for value assignment
    • significant (p = 0.0282)
  
  • 16 of 32 (from study B) used appropriate models for reference assignment
    • significant (p = 0.0002)
STUDY C

• Results:
• Compared test results to those from Studies A and B

<table>
<thead>
<tr>
<th>Value Assignment</th>
<th>Reference Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>The mental models used in the ‘value assignment’ experiment</td>
<td>The mental models used at end of the course</td>
</tr>
<tr>
<td>Pre-test</td>
<td>Post-test</td>
</tr>
<tr>
<td>Viable</td>
<td>–</td>
</tr>
<tr>
<td>Non-viable</td>
<td>Viable</td>
</tr>
<tr>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>The mental models used in the ‘reference assignment’ experiment</th>
<th>The mental models used at end of the course</th>
<th>Number of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>Post-test</td>
<td></td>
</tr>
<tr>
<td>Viable</td>
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<td>Non-viable</td>
<td>Viable</td>
</tr>
</tbody>
</table>
• Potential confounding factors
  • Some non-viable models may not have been challenged appropriately by the cognitive conflict portion
  • Interest in study participation might select students with higher drive, or encourage pressure to learn

• Conclusions
  • For straightforward concepts (assignment), cognitive conflict did not seem to add much
  • For harder concepts (reference), cognitive conflict had a more obvious impact
  • Analysis points to success for the proposed teaching model in terms of student understanding
DISCUSSION

- What are your thoughts on the cognitive conflict and constructivist model?

- Have you had experience with these concepts, either in class or otherwise?

- How would you utilize the proposed teaching model in your classrooms or field of study?

- Are there any areas that would not benefit from the proposed model?
Thank you for your attention and thoughts!