Educational Technologies
WS2008

Meta-Cognitive Support
(Help!)

Bruce M. McLaren
Senior Researcher, DFKI
Course Syllabus

28.10.2008 Introduction and overview
04.11.2008: Intelligent tutoring systems (1) - Cognitive Tutors
11.11.2008: Intelligent tutoring systems (2) – ActiveMath
18.11.2008: Student modelling
25.11.2008: Student modelling
   : Pedagogical components, instructional planning
02.12.2008: Error diagnosis and feedback
09.12.2008: Meta-cognitive support (1) – Help
16.12.2008: Meta-cognitive support (2)
13.01.2009: Collaborative learning technologies
20.01.2009: Multi-Media Learning principles
27.01.2009: Web-based systems
03.02.2009: Educational data mining
10.02.2009: Project presentations by students
Overview of the Lecture

▶ Overview of Meta-Cognition
  ▶ What is Meta-Cognition?
  ▶ Why is it important?

▶ Discussion About Help Seeking
  ▶ What do you think is good and bad help seeking?

▶ Case Study of a particular Meta-Cognitive Tool: The HelpTutor (Aleven, McLaren, Roll, Koedinger)

▶ Summary and Conclusions
Metacognition - What is it?

Metacognition refers to higher-order thinking and active control over the cognitive processes of learning

“thinking about thinking”

The term "metacognition" is most often associated with Flavell (1979, 1987) who says metacognition consists of:

metacognitive knowledge and
metacognitive experiences or regulation

E.g. 1: Planning how to approach a learning task (“Should I start reading here or here?”)

E.g. 2: Monitoring comprehension (“Let’s see now, did I really understand those calculus problems I just did?”)

E.g. 3: Evaluating progress toward completion of a task (“Looks like I still need to learn about this aspect …”)
Metacognition - Why is it Important?

“A ‘metacognitive’ approach to instruction can help students learn to take control of their own learning…”


“Metacognitively aware learners are more strategic and perform better than unaware ones” [Pressley & Ghatala, 1990]

“Metacognitive awareness enables individuals to plan, sequence, and monitor their learning in a way that directly improves performance” [Schraw & Dennison, 1994]
Metacognitive Support in Instructional Systems

▶ Challenges:
- There is no operational model of metacognition!
- How do we assess students’ metacognitive states?
- How do we design metacognitive instructional activities?
- How do we avoid cognitive overload?

▶ Some examples of instructional systems from ITS literature:
- MIST: strategies planning, evaluation of knowledge and revision [Puntambekar & du Boulay, 1999]
- SE-Coach: Self-explanations [Conati & Vanlehn, 2000]
- MIRA: Support for various stages of metacognition [Gama, 2004]
- Cognitive Tutors: Gaming the system [Baker 2006]
Phases of Self-Regulation (i.e., Meta-cognition) (Zimmerman & Schunk)

Forethought
- Task Analysis
  - Goal Setting
  - Planning
- Self-Motivation
  - Beliefs
    - Self-Efficacy
    - Outcome Expectations
    - Value
    - Goal Orientation

Performance
- Self-Control
  - Self-Instruction
  - Imagery
  - Task Strategies
  - Attention Focusing
- Self-Observation
  - Metacognitive Self-Monitoring
  - Self-Recording

Self-Reflection
- Self-Judgment
  - Self-Evaluation
  - Causal Attribution
- Self-Reaction
  - Self-Satisfaction
  - Affect
  - Adaptive (Defensive?)

Empirical Evidence for correlation within and causation across, e.g., writing Performance

- Self-efficacy correlated with goal setting (Zimmerman & Bandura, 1994)
- Performance phase strategy causally linked to Self-Reflection phase (e.g., self-satisfaction) (Zimmerman & Kitsantas, 1997)
- Self-Reflection phase predictive of Forethought phase self-efficacy (Zimmerman & Kitsantas, 1999)
Proposed Model for Problem Solving Environments (Artzt & Armour-Thomas, 1998)

**Conceptual Stages of Problem Solving**

- **Forethought**
- **Performance**
- **Self Reflection**

**Cognition**

- Domain knowledge, problem solving heuristics, domain-related strategies, etc.

**Metacognition**

- Knowledge Monitoring
- Strategies Search
- Monitoring and Regulation
- Checking and Revising
- Evaluation of Problem Solving Experience
- Other metacognitive skills

Source: Bruce McLaren, Erica Melis, Vincent Aleven, Ido Roll

Educational Technologies WS 2008/09
Specific Example of Metacognition

Polya’s Framework

Source: Bruce McLaren, Erica Melis, Vincent Aleven, Ido Roll
Specific Example of Metacognition

Find the volume of the frustum of a right pyramid with a square base, given:

- the altitude of the pyramid,
- the altitude of the frustum,
- the length of a side of its lower base, and
- the length of a side of its upper base
Step 1: Evaluate the problem (i.e. Forethought)

What is the goal?
▷ Volume of the frustum

What is given?
▷ Altitude of the pyramid (h1)
▷ Altitude of frustum (h2)
▷ Length of the upper base (b)
▷ Length of the lower base (a)

Do I know how to do this?
▷ Yes! I am good at these types of problems … (self-efficacy)
Can you solve directly?

▷ Let’s say you don’t know the volume of a frustum

But is there a related problem?

▷ Yes, volume of a right pyramid
▷ The volume of a right pyramid can be obtained as follows:

\[ V = \frac{1}{3} a^2 h \]

Can you restate the problem?

▷ Find the volume of the large right pyramid minus the volume of the small right pyramid
Step 3: Carry out the plan (i.e., Performance)

- Calculate the volume of large pyramid
- Calculate the volume of small pyramid
- Subtract the second from the first
- As you move through these steps, you might:
  - focus attention on the subproblems → “attention focusing”
  - monitor or check your steps → “metacognitive self-monitoring”
Step 4: Look back (i.e., Self Reflection)

- How general is this approach? This technique can be applied to other problems such as:
  - Find the area of a donut, given the radius to the inside and outside
  - Find the volume of the outer portion of a cylinder with another cylinder inside it, given the radius of both the inner and outer cylinders and the cylinder length

- How did I do on this problem? ("Self-Judgment")
  - “I handled this one pretty well; this was probably the only/best way to solve this!”
Help Seeking: A Special Case of Self-Regulation and Metacognition

Help seeking is a particular type of metacognition

- An important form of self-regulated learning

Important questions related to help seeking & problem solving

- When should you seek help?
- When should you solve on your own?
Thought Exercise …

Before I start discussing help seeking, though, let’s see what your thoughts and ideas are about it…

Take 10 minutes to consider and to write down your responses to the questions on the next slide.

Then take another 5 minutes to discuss your thoughts with one other person in the class (group of 3 if we have an odd number)
Help Seeking: A Special Case of Self-Regulation and Metacognition

How would you describe students who:
- seek help?
- do not seek help?

What would you say are …
- the (potential) benefits of help seeking?
- the (potential) costs of help seeking?
Potential Benefits and Costs of Help Seeking

Potential Benefits?

- Greater likelihood of success
- Increased knowledge
- Improved collaboration with others

Potential Costs?

- No real learning, just finding the answer
- Threat to self-esteem
- Indebtedness to helper
- Embarrassment
Research on Help Seeking and Learning in Instructional Systems

- A bit different than regular help seeking...

- On-demand help often used ineffectively

- Better learning when help is used effectively
  - **Correlational**: positive correlation between help use and learning (Bartolomé, Stahl, Pieschl, & Bromme, 2006; Wood & Wood, 1999)
  - **Causal**: adding on-demand help leads to better learning (Renkl, 2000; Schworm & Renkl, 2002a; 2002b)

- But
  - Lab studies (limited external validity)
  - Most studies do not evaluate the effect of *instruction* on help seeking
Case Study: The HelpTutor
(Aleven, McLaren, Roll, & Koedinger, 2006)

▶ **Hypothesis**: computer-based tutoring of help seeking prepares students for better future learning

▶ **Methodology**: develop Cognitive Tutor that provides feedback on help seeking

▶ A series of classroom experiments in a science of learning center
We’ve already seen evidence of Cognitive Tutor success at cognitive level …

- Full year classroom experiments
- Replicated over 3 years in urban schools
- In Pittsburgh & Milwaukee

Results:
- 50-100% better on problem solving & representation use.
- 15-25% better on standardized tests.

Goals of Metacognitive Tutoring – and the HelpTutor in particular

- Capture & correlate help-seeking behavior
- Improve help-seeking behavior
- Promote domain learning
- Promote future help seeking
Motivation: Poor help seeking with the Geometry Cognitive Tutor in classrooms

Context-sensitive hints, given at the student’s request

Glossary of geometry knowledge
Example hint sequence

1. As you can see in the diagram, Angles LGH and TGH are adjacent angles. Together they form line HI. How can you use this fact to find the measure of Angle TGH?

2. Look in the Glossary for reasons dealing with adjacent angles.

3. Some rules dealing with adjacent angles are highlighted in the Glossary. Which of these reasons is appropriate? You can click on each reason in the Glossary to find out more.

4. If two angles form a linear pair, the sum of their measures is 180 degrees. Angle TGH and Angle LGH form a linear pair.

5. The measure of Angle TGH plus the measure of Angle LGH is equal to 180 degrees.

6. The measure of Angle TGH is equal to 180 degrees minus the measure of Angle LGH.

7. \( m\angle TGH = 180^\circ - m\angle LGH \)
Example Glossary item

The measure of an exterior angle of a triangle is equal to the sum of the measures of the two remote interior angles.

**Example**

Given: Angle 1 is an exterior angle of \(\triangle ABC\). If \(\angle 2 = 75^\circ\) and \(\angle 3 = 40^\circ\), then \(\angle 1 = 75^\circ + 40^\circ = 115^\circ\).
Evidence of Poor Help Seeking
(Aleven & Koedinger, 2002)

- Help abuse - use of hints to get answers without understanding
  - When asking for a hint, students go all the way to the bottom-out hint 82% - 89% of the time
  - Spend 2.3 seconds per intermediate hint

- Help avoidance
  - Students often do not ask for a hint even after multiple errors on a step
  - Glossary used on 2.7% of answer steps
Hypothesis

- Computer-based tutoring of help seeking leads to
  - better help seeking,
  - better learning, and
  - better future learning

- Novel approach:
  - A Help Tutor Agent provides tutoring on help seeking - serves as adjunct to Cognitive Tutor
The Help Tutor

And now a movie of the Help Tutor in action ...
Meta-Cognitive Model captures good help-seeking behavior and forms basis of HelpTutor

- **START**
- Spend time to think about step
  - **Familiar at all?**
    - **NO**
      - **Ask for hint**
      - **Spend time to read hint**
    - **YES**
      - **Try step (i.e., enter answer)**
        - **NO**
          - **Clear how to fix?**
          - **NO**
            - **Tutor says correct?**
              - **NO**
                - **DONE**
              - **YES**
                - **DONE**
          - **YES**
            - **Clear how to fix?**
            - **NO**
              - **Tutor says correct?**
                - **NO**
                  - **DONE**
                - **YES**
                  - **DONE**
            - **YES**
              - **Hint helpful?**
                - **NO**
                  - **DONE**
                - **YES**
                  - **DONE**

Implemented by 57 production rules, including 32 “bug rules”
Taxonomy of help-seeking “bugs”

Frequency of bugs

Source: Bruce McLaren, Erica Melis, Vincent Aleven, Ido Roll

Educational Technologies WS 2008/09
HelpTutor Architecture
Poor help seeking modeled by “buggy rules”

Example bug rule:

If the goal is to decide what action to take
and the step is not familiar (i.e., the probability that the student knows the skill(s) involved in the step is less than $0.4$)
and the student has not seen all hints for this step

Then try the step

Error feedback message:
“A hint might help you tackle this difficult step.”
Student Reaction ...

Help Tutor: “You probably know enough to try to solve this step without a hint”

Student X: “I hate this tutor!”

Student Y: “Because it makes you do the work yourself…”
Assessing Help-Seeking Knowledge

- **Declarative knowledge**
  - Do students know the help-seeking “facts” better?

- **Procedural knowledge**
  - Do students **apply** the help-seeking skills better?

- **Transfer**
  - Does the effect **hold** in other learning environments?
Assessing Help-Seeking Knowledge

- **Declarative knowledge**

1. You tried to answer a question that you know, but for some reason the tutor says that your answer is wrong. What should you do?

   - [ ] The Tutor is probably wrong. I will retype the same answer again.
   - [ ] I will ask for all hints until I get it right and move on.
   - [ ] I will review my calculations. Perhaps I can understand my mistake?

- **Procedural knowledge**

- **Transfer**
Assessing Help-Seeking Knowledge

- Declarative knowledge

- Procedural knowledge
  - Log file analysis

- Transfer
Assessing Help-Seeking Knowledge

- Declarative knowledge
- Procedural knowledge
- Transfer
Experimental Design #1

Suburban school
Teacher a
Class a1
30 students
Class a2

Urban school
Teacher b
Class b1
30 students
Class b2

Pretest
3 weeks x 2 hours
Treatment
Posttest

Source: Bruce McLaren, Erica Melis, Vincent Aleven, Ido Roll
Educational Technologies WS 2008/09
Experimental Results #1

- Capture / Corr. help-seeking errors
- Improve help-seeking behavior
- Promote domain learning
- Promote future help seeking

- Frequency of help seeking errors: 17%
- Correlation with learning: 0.42 (p<0.05)
Improving Help-Seeking Behavior – Yes, a bit...

- A minor overall behavior modification:

  - Bottom out hint rate: 72% (control) vs. 46% (Help) \( P<0.0001 \)
Improve domain learning – No...

Both conditions improved from 36% to 41% (p<0.02)

Letting results get in the way of good theory

Promote domain learning
Improve help-seeking behavior
Capture / Corr. help-seeking errors
Future help seeking – No...

No evidence for metacognitive (i.e., help-seeking) learning:
  - No improvement in declarative or transfer tests
  - No data from following unit

Some evidence for following recommendations
  - Step function vs. learning curve
  - Hint recommendations were followed (p=0.02), but not try-step recommendations
Discussion of Results

- Improve help-seeking behavior
- Capture / Corr. help-seeking errors

Captured and improved help-seeking…
But not so successful with learning or future help seeking

- Cognitive overload  -> Preparatory sessions
- Lack of awareness  -> More help-seeking instruction
- Local message wording  -> Stress principles
- Deep-rooted behavior  -> Longer study
- Faulty help-seeking model  -> Log-file analysis
- Ineffective hints  -> Shorter sequences

- Teach principles of help seeking prior to practice
  - Reduce domain-level cognitive demands during initial help-seeking practice

- Reinforce principles of help seeking during practice
  - “It may not seem like a big deal, but hurrying through these steps may lead to later errors. Try to slow down.”
  - “Struggling is part of the learning process. You will not learn by guessing or abusing hints, even if you get the answer right”

- Have students’ self-assess their domain skills/knowledge
The Help-Seeking Support Environment

The Help Tutor

Domain level instruction

Tutored problem solving
The Help-Seeking Support Environment

<table>
<thead>
<tr>
<th>The Help Tutor</th>
<th>Domain level instruction</th>
<th>Tutored problem solving</th>
</tr>
</thead>
</table>
Declarative help-seeking instruction

▶ 4-minute video

▶ A teacher-led interactive discussion

[White and Frederiksen, 1998]
The ability to correctly self-assess is correlated with strategic use of help [Tobias and Everson, 2002]

1. Can you answer this problem without making errors?
2. Answer
3. Did you think you could solve it without errors?
4. Did you succeed in solving it without errors?
5. Did you correctly evaluate your knowledge?
6. Will you need a hint the next time you get a similar problem?
Experimental Design #2

Control

Domain instruction
Pretest 1

Problem solving with Geometry Tutor (w/o Help Tutor)

Posttest 1, pretest 2

Break

Domain instruction

Problem solving with Geometry Tutor (w/o Help Tutor)

HSSE

- help-seeking instruction

- Self assessment sessions

Diagram not drawn to scale

Self-assessment takes about 10% of total problem solving time
Experimental Results #2

1. Problem solving
2. Self-explanation (i.e., reasons)
3. Data Insufficiency
4. Conceptual understanding
5. Hint usage in transfer environment
6. Declarative help-seeking knowledge

* Sig. Result
Summary and Conclusions

Metacognition: Higher order thinking and active control over the cognitive processes engaged in learning

- Educational psychology models have been developed to illustrate stages
- Many believe good metacognition is essential to learning; some empirical evidence exists to support this belief
- A few systems have been developed to support

Help Seeking: A special case of metacognition; self-understanding of when help is needed
Summary and Conclusions (Cont.)

Research question: Effectiveness of meta-cognitive instruction focused on help seeking

- Problem: poor help use
- Likelihood of success: evidence of relations between help seeking and learning

The HelpTutor Project:

- A model of “ideal” help seeking
- Captured and improved help seeking, at least in some respects in both experiments, but not yet shown to help
  1. domain learning and
  2. future help seeking

- This is a very hard problem!
Thank You!