Educational Technologies
WS2006

Cognitive Tools

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Approximate Plan of the Course

18.10. Introduction
25.10. Introduction to ActiveMath
   XML- Knowledge Representation
8.11. Student Modelling
15.11. Web technologies and security
22.11. Tutorial Planning and instructional design
29.11. Media Principles
6.12. Interactive exercises
13.12. Authoring tools, CTAT
20.12. Diagnosis: model tracing and domain reasoning

10.1. Diagnosis: constraint based
17.1. Tutorial dialogues
24.1. Action analysis and Machine Learning techniques
31.1. Cognitive tools
7.2. Meta-cognitive support
14.2. Student projects
Outline

1. Repeat Cognitive Theory and Media Principles
2. From Cognitivism to Constructivism
3. Cognitive Tools
4. Examples
   - simulations
   - learning diaries
   - concept mapping
“The design of e-learning courses should be based on cognitive theory of how people learn and on scientifically valid research studies.”

This also implies the design of e-learning software.

Don’t rely on information delivery theory.
How do People Learn?

Mental processes transform information into knowledge and skills in memory

- **Information processing through channels:**
  - visual, auditory, haptic
- **Working memory** is a limited capacity memory device
- Learning = new knowledge and skills in working memory have to be integrated with existing knowledge in long-term memory
  - ... called **encoding**.
- Active processing in working memory is called **rehearsal**.
- Retrieve skills from long-term memory back into working memory is called **retrieval**.
How e-Lessons Affect Human Learning

- Use instructional methods to guide information
- ... through the sensory of working memories
- ... to incorporated information into the existing knowledge in long-term memory:

1. Selection and focus
2. Reduce cognitive load
3. Integration by encoding and rehearsal
4. Retrieval
5. Management via meta-cognitive skills

Source: Martin Homik   Educational Technologies WS 2006/07
Media Principles (Summary)

- **Multimedia principle**
  - Use words and graphics rather than words alone

- **Contiguity principle**
  - Place corresponding words and graphics near each other

- **Modality principle**
  - Present words as audio narration

- **Redundancy principle**
  - Presenting words in both text and audio narration can hurt learning

- **Coherence principle**
  - Adding interesting material can hurt learning

- **Personalization principle**
  - Use conversational style and virtual coaches
Other means to reduce cognitive load

- Training of patterns (Processes)
- Offer different representations
- Change between Abstractness and Concreteness
- Provide examples and counterexamples
Learning Theories (look back)

- **Objectivism**
  - Information is externally referenced and delivered

- **Behaviorism**
  - Stimulus/Response Coupling

- **Cognitivism**
  - Discover and model mental processes (cognitive theory)
  - Mainly reduce cognitive load

- **Constructivism**
  - No information delivery by teacher/tutor
  - Support creation of new knowledge that reflects the student’s comprehension and conception of the information
  - ... knowledge is internally created!
  - Learner is in control (self-guided learning), Jonassen, 1981
Mapping Technologies to Learning Theories

Jonassen, 1981
What is a Cognitive Tool?
Definition

First introduced by Lajoie and Derry (1993)

Instruments included in a learning environment allowing learners to make cognitive processes and their results explicit.

They support cognitive processes by relieving working memory or

... presenting a structure for performing the process.

Also, they can perform a cognitive process automatically, allowing the learner to concentrate on another process first. (Joolingen, ITS 98)
Functions of Cognitive Tools

- Do (automatically) complex computations (CAS)
- Externalize reasoning processes (diaries)
- Visualize reasoning processes (concept maps)
Key Questions

- How to design cognitive tools starting from the theory on discovery learning?
- What are the characteristics of cognitive tools in terms of their impact on the learning process?
- How to integrate cognitive tools in a simulation environment?
Discovery Learning

- **Constructivist approach**

- **Construct own knowledge by**
  - Experimenting with a domain
  - Inferring rules from the results of the experiments

- **In practice, hard to prove this theory**
  - Assumption: Learners need also assistance and guidance

- **Specific skills are needed:**
  - Discovery skills: hypothesis generation, experiment design, prediction, data analysis (De Jong & Van Joolingen, 1994)
  - Regulative skills: planning and monitoring (Njoo & De Jong, 1993)

- **Skills itself are learning goals**
Dilemma

Discovery requires that the learner has sufficient freedom to select and interpret information.

Any kind of support that limits this freedom in principle disrupts the nature of the discovery process.

Check models of discovery learning:

- Newell and Simon (1972)
- Simon and Lea (1974)
- Qin and Simon (1988)
- Klahr and Dunbar (1988)
Discovery Described as Dual Search Spaces

- **Hypothesis space**
  - Space of rules that are possible descriptions of the domain
  - Hypotheses can direct the search in experiment space

- **Experiment space**
  - Instance space which represents the data that can be collected in the domain
  - Results of the experiments can influence the search for new hypotheses
Search Strategies in Dual Search Spaces

**Theoriest Strategy:**
1. Start with hypotheses and use experiment space for confirming or rejecting evidences.
2. If rejected, reformulate hypotheses and restart experiment

**Experimenter Strategy:**
1. Collect data
2. Formulate Hypothesis

**Observation:**
- Main selection criterion lies in the prior knowledge
Decomposition of Hypothesis Space

- Dual model is not modulo the learner/discoverer
  - … in terms of prior knowledge
- Reasoning inside LSS = Considering different alternatives
- Crossing boundaries = Consider a new relationship

De Jong, Van Joolingen, 1998
Explaining Unsuccessful Discovery

Learning processes may themselves be problematic (transformative/discovery, regulative)
  - Transformative processes relate directly to dual spaces:
    - … generalization/specification of hypotheses
    - … what kind of hypotheses to state
    - … what kind of experiments to perform

Constraints on both spaces can prevent discovery
  - … e.g. only confirmation of hypotheses

Learners cannot find constraints:
  - … e.g. vary only one variable at a time
Hypothesis Generation Sketchpad (SMISLE)

Problem: Lack of knowledge on basic elements of a hypothesis
- Learners use bad syntax for hypothesis formulation
- Lack of prior knowledge
Monitoring Experiments

- Design and manage multiple experiments
- … relieves memory and cognitive load.
- … reactive system
Hooking Intelligent Support

- It is hard to track what a learner does and thinks in an open learning environment
- … how to provide adaptivity?
- Base it on externalized data on learning processes
  - Provide adaptivity, feedback
  - Monitoring tool could advise to do a specific experiment based on the predictions of a hypothesis
  - Simulation could be asked to constrain experiment space
  - Hypothesis sketchpad can analyze hypotheses
  - … or constrain the learner
Hooking Intelligent Support: Feedback

- Quality of the experiments
  - Here, no conclusion can be drawn

- Relation of the experimental results to the current hypothesis
  - Here, experiments support hypothesis
SimQuest Learning Environment

- Modularize in components
- All components have a common/shared context
  - Here: variables represent express the current state and represent the inputs and outputs
SimQuest Learning Architecture

Instructional Measures

Learner Interface

Simulation Context

Simulation Model
Simulations
SimNerv

- Stimulator
- Oscilloscope
- recording chamber
- Two "frog sciatic nerves"

- physiology course for medical and human-biology students
- http://www.clabs.de

Source: Martin Homik      Educational Technologies WS 2006/07
Driving Academy
Flight Simulator, Auckland, New Zealand
Generic Large Aircraft Simulator System Project
Learning Diaries
Typical Situation
Identify/Close Learning Gaps

- ... by learning diaries (studies provide evidence)
- ... naïve learning logs are sub optimal wrt. (meta-) cognitive learning (Nückles et al., 2004)
- ... Prompting: answering questions
  - ... can increase learning as they help to activate background knowledge (Pressley et al., 1992)
  - ... *the whole of a person’s knowledge, including explicit and tacit knowledge, metacognitive and conceptual knowledge* (Dochy & Alexander, 1995).
  - ... (Meta-) Cognitive prompts (Berthold et al., 2006)
Electronic Learning Diaries

- Electronic diaries exist for a long time
- Weblogs became a popular platform
  - Use blogs for writing learning diaries
- Knowledge Bloggers report about:
  - Current work
  - Research ideas
  - Learning progress
My Summary: Decision Theoretic Tutors

This is my summary of Stephen's Talk on Decision Theoretic Tutors.

I thought that the concepts presented here were very interesting because they're quite different to other approaches. The tutors I know rely on good exercise construction and error or help messages to keep a user working. That is, a human exercise author is responsible for keeping the user happy and motivated. If a user is getting unhappy, because he can't do an exercise as well as he likes, then there is usually no way to react to this within the exercise. And the user will probably stop working on the exercise or with the tutor itself.

To counter this, DT-Tutors have a student Model that does not only contain knowledge and relevance networks, but also some information about the student's 'feelings'. This includes the students feeling of indepenedence (from system help) and morale.

Now, the knowledge network is rather standard stuff, i.e. all the parts of the problem solution graph the student already knows.
Example

What difficulties arose during problem solving?

My main problem was, that I did not understand what was meant by ...

Which learning objects were most helpful?

Definition of the derivative, resp., differential quot...
Cognitive Prompts

 Organisation. What is the story line of the talk? Describe the motivation, the goals, and the path to the goals.

 Elaboration. Make up own examples, counter examples or illustrations. Did you come across the presented techniques in a different context? If yes, where?

 Critical Reflection. What did you find interesting, useful, convincing, inspiring? Is there anything you criticise?
Metacognitive Prompts

- *Monitoring.* What did you not understand?
- *Self-diagnosis.* What is the likely reason?
- *Self-regulation.* How would you overcome your deficiency?
Concept Mapping
Goals

Making knowledge explicit by spatial visualisation:
- Reduce cognitive load
- Contribute to understanding
- Contribute to knowledge acquisition
- Contribute to knowledge management
Types of spatial configurations (1)

sequence

cluster

Mit freundlicher Genehmigung von Sigmar-Olaf Tergan, IWM-KMRC
Types of spatial configurations (2)

hierarchy

[Diagram showing a hierarchical structure with various nodes and connections]
Types of spatial configurations (3)

Web-like organisations (see Wiegemann, Dansereau et al., 1992)
Types of spatial configurations (4)
Representation focuses

... kind of knowledge elements:
- Conceptual knowledge
- Multi-media content knowledge
- Annotations
- Knowledge resources (URIs)

... kind of relation between knowledge elements:
- Single lines connecting two nodes
- Lines with arrow head
- Semantic links (labelled links)
- Hyperlinks
Spatial representations statements

- Are configurations or ways ideas are “spread out” on a page or display
- Provide a framework to organise and structure information (O’Donnell, 2003)
- Match the central tendency of the brain for structuring and visualising knowledge in mental images and mental models (Kosslyn, 1980; Johnson-Laird, 1993; Kintsch 1998)
Spatial representations statements

- Facilitate cognitive processing by allowing for artifact-based reasoning (Norman, 1991)
- Are easier to search and navigate than traditional text displays (Larkin & Simon, 1987)
- Can provide spatial and verbal cues that aid both storing and remembering information (Paivio, 1986)
What are Mind Maps?

- **Bases on:** human brain is an associative network
  - Stimulates associative and creative thinking
  - Terms are structured according to their thematic proximity
  - Used for brainstorming; spontaneous creation and concatenation of ideas
  - Start with a central idea
  - … and spread branches to related terms
  - … relations between terms are usually undefined
  - … tree-like structure
Example: Mind Map with “Mind Manager”

Use this map as a guideline and define your goals for each day of the week.

This map provides partial information and by no means is a complete.
Example Mind Map
Example Mind Map

Source: Martin Homik Educational Technologies WS 2006/07
What are Concept Maps?

- Base on: human brain consist of a (hierarchically) structured network of concepts
  - Stimulates analytical and reflective thinking
  - (web-) network structure and node positions are determined by the logical relations between concepts
  - Node positions used to relate hierarchies
  - Edges used to represent relations

Pioneer in Concept Mapping research: J.D. Novak

“Meaningful learning involves the assimilation of new concepts and propositions into existing cognitive structures.”
Example: Concept Map

Source: Martin Homik       Educational Technologies WS 2006/07
Functions

- Reduction
- Structuring
- Visualising
- Communication
- Elaboration
- Motivation
Use for learning and instruction

- Instructional strategy (lecture aid)
- Instructional strategy for fostering complex problem solving
- Learning strategy for fostering comprehension, knowledge acquisition, self-regulated learning
- Tool for knowledge diagnosis and evaluation of learning success
- Navigational tool in hypermedia-based programs (Gaines & Shaw, 1995)
Use for Knowledge Management

- For comprehensive modeling of knowledge (Alpert & Gruenenberg, 2000)
- For capturing and retaining knowledge in an enterprise (Canas, Leake & Wilson, 2003)
- For knowledge communication and sharing in collaborative work (Mandl & Fisher, 2000)
- For providing direct interactive access to knowledge and knowledge resources (Coffey et al., 2002)
- For maintaining and updating knowledge (Coffey et al., 2002)
Mapping Tools (1)

- Mind Manager (Mindjet)
- Inspiration (Inspiration Software Inc.)
- Visual Knowledge Builder (Texas A&M University)
- Smart Ideas (Smart Technologies)
- Knowledge Manager (Hypersoft)
- Axon (Axon Research)
- cMap Tools (Institute for Human and Machine Cognition, Univ. West Florida)
- Smart Draw (SmartDraw.com)
- Mind Mapper (SimTech USA Corp.)
- Visual Mind (Norcan Data)
- The Brain (The Brain Technologies Corp.)
- OpenMind (Matchware)
- CoolModes (Collide)
- CognitiveTools (EMindMap)
- VModel (?)
- FreeMind (Sourceforge)
iCMap

Demo
AM: Knowledge Representation

Abstract concept level:
• Symbols

Content concept level:
• Definitions
• Theorems

Satellite level:
• Examples
• Exercises
AM: Knowledge Representation:

Abstract concept level:
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Source: Martin Homik    Educational Technologies WS 2006/07
Verification

1. Against knowledge base
2. Against authored exercise
3. Deduction
Deductive Relation: Transitivity

Abstract concept level:
• Symbols

Content concept level:
• Definitions
• Theorems

Satellite level:
• Examples
• Exercises

Source: Martin Homik    Educational Technologies WS 2006/07
Deductive Relation: Transitivity

Abstract concept level:
- Symbols

Content concept level:
- Definitions
- Theorems

Satellite level:
- Examples
- Exercises
Deductive Relation: Equivalence

Abstract concept level:
• Symbols

Content concept level:
• Definitions
• Theorems

Satellite level:
• Examples
• Exercises

Source: Martin Homik   Educational Technologies WS 2006/07
Fault Tolerance

Abstract concept level:
• Symbols

Content concept level:
• Definitions
• Theorems

Satellite level:
• Examples
• Exercises
iCMap Example
iCMap Feedback
Local Feedback
Take Home Message

- Cognitivism + Constructivism + Discovery Learning: Cognitive Tools
  - Reduce cognitive load
  - Support encoding and rehearsal in working memory
  - Support implicit knowledge creation
  - Externalize knowledge
  - Visualize knowledge
  - Self-guided playful learning
  - Obey a learner’s individual ways of knowledge creation and conceptualisation of information
Literature


- Ruth C Clark, Richard E. Mayer, e-Learning and the Science of Instruction


- Michael W. Eysenck, Mark T. Keane: Cognitive Psychology


Literature


- G. Polya, *How to solve it*

**Surveys on mapping technologies:**
- Jonassen et al., 1993
- Jüngst & Strittmatter, 1995
- Fischer, 1998
- Mandl & Fischer, 2000
- O’Donnell, 2003
- Nückles, Gurlitt, Pabst, and Renkl, *Mind Maps and Concept Maps*, (in German; lots of other English literature)