Scaffolding inquiry learning; How much intelligence is needed and by whom?

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Topics

- Inquiry (scientific discovery) learning
- Computer simulation based learning environments
- How to make \textit{simulation based inquiry} learning successful?
  - Scaffolds
  - Conditions
- Is intelligence needed?
Inquiry Learning

Inquiry is an approach to learning that involves a process of **exploration**, that leads to **asking questions** and making **discoveries** in the search for **new understandings**.

*Based on “Foundations”, Vol, 2, NSF, 2000*
Technology enhanced inquiry learning

- TEL environments
  - Simulations, games, adventures
  - Remote labs
  - Data sets
  - Hypermedia

- Simulations
  - Model of a system or a process
  - Students have to infer this model
  - They change values of input variables and observe values of output variables
An example simulation
SimQuest
An example ZAP simulation
What are ZAPS: The Norton Psychology Labs?

Want to expose your students to the scientific process but don’t have time for a lab! The solution is ZAPS!

$28 stand-alone! $10 with a Norton book!

What are ZAPS: The Norton Psychology Labs?

Perfect for introductory psychology or cognition courses, ZAPS: The Norton Psychology Labs is a set of 45 interactive computer experiments that allow students to experience psychological phenomena and classical experiments in exciting and interactive online environment. Each ZAP is designed to be completed in 15 to 30 minutes.

ZAPS cover a wide range of topics in psychology. There are ZAPS that cover biological and physiological phenomena, such as the gate-control theory of pain, and ZAPS that cover findings from social
Co-Lab

Cognitive tools

Simulation

Control display

Graphs

Traffic light to request and pass control

Chat

Repository
Mayer
Should there be a three-strikes rule against pure discovery learning? (American Psychologist, 2004)

- Overview of studies in ‘problem solving’, ‘conservation strategies’, and ‘programming’
- Pure discovery learning is not effective because learners may not be confronted with the to-be-learned material
- Guided discovery is more effective than pure discovery learning or expository teaching
Klahr and Nigam
The equivalence of learning paths in early science instruction: effects of direct instruction and discovery learning

(Psychological Science, 2004)

- Students experimented with a ball rolling from a wooden ramp, one group received no support at all, in the other group an experimenter gave examples of good and poor experiments, explained differences between experiments, etc.
- The ‘support’ group outperformed the ‘pure discovery’ group on use of CVS strategy (but still 23% of the kids in the pure discovery group learned CVS)
- On a later test there was no differences between kids having learned through ‘direct instruction’ and kids having learned by ‘pure discovery’
Conclusions so far

- Pure discovery does not work
- Support/scaffolds should be present to make inquiry productive
- Learning goals can be very different
- Domains can be very different
- Students can be very different
- Definitions (discovery, inquiry, direct instruction) can be very different
- Therefore, we need a better view on what constitutes inquiry learning
<table>
<thead>
<tr>
<th>Transformative processes</th>
<th>Regulative processes</th>
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<tbody>
<tr>
<td>Orientation</td>
<td>Planning</td>
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<tr>
<td>Hypothesis generation</td>
<td>Monitoring</td>
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<tr>
<td>Experimentation</td>
<td></td>
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<tr>
<td>- Experiment design</td>
<td></td>
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<tr>
<td>- Prediction</td>
<td></td>
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<tr>
<td>- Data interpretation</td>
<td></td>
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<tr>
<td>Conclusion</td>
<td></td>
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</tbody>
</table>
Problems in discovery

- Poor hypotheses
- Ineffective experiments
- Engineering approach
- Mistakes in data interpretation
- No planning and monitoring (floundering)
- etc.
Scaffolds

- Assignments
- Explanations
- Model sequencing
- Monitoring facilities
- Hypothesis scratchpad
- Prompts
- Data interpreters
- Etc. etc.

2004 special issue of the JLS
2004 LEA book on science environments
by Linn, Bell, and Davis
Example of an assignment

Does an elevation level (up and/or down) influence the size of the moment?

Answers:
- a. yes, but only an upward movement
- b. yes, but only a downward movement
- c. yes, movement upwards as well as downwards
- d. neither has influence on the moment

This is not right.
Try to find the right answer by changing the elevation level and looking at the size of the moment.
If the movement is too fast, you can use the "Simulation delay".
Results of scaffolding

- Structuring the environment helps
  - Assignments
  - Ready made hypotheses
  - Overall structures

- Providing background information is necessary

- Model progression is not always helpful

- Adaptive scaffolding
- Scaffolded collaboration
Adaptive scaffolding
Simulation on collisions

Elastic collision

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>M1:</td>
<td>0.500 kg</td>
<td>-0.50 m</td>
<td>-2.0 m/s</td>
<td>0.00 m/s</td>
<td>0.00 J</td>
</tr>
<tr>
<td>M2:</td>
<td>0.500 kg</td>
<td>-6.20 m</td>
<td>0.0 m/s</td>
<td>-2.00 m/s</td>
<td>-1.00 kg m/s</td>
</tr>
</tbody>
</table>

\[ t = 7.4 \text{ s.} \quad \text{total:} \quad -1.00 \text{ kg m/s} \quad 1.00 \text{ J} \]
The assignments used

Try to find out how changing the initial velocity of the green ball ($v_1$) influences the kinetic energy of the ball ($U_{k1\_after}$) after the collision against the blue ball.

Start with selecting a hypothesis you are going to investigate.

Investigate whether this hypothesis is correct or incorrect. Based on the result decide which other hypotheses could be correct and which hypotheses are bound to be incorrect.

1. No relation exists between $v_1$ and $U_{k1\_after}$
2. If $v_1$ increases, then $U_{k1\_after}$ decreases
3. If $v_1$ becomes twice as great, then $U_{k1\_after}$ becomes twice as small.
4. If $v_1$ becomes twice as great, then $U_{k1\_after}$ becomes four times as small
5. If $v_1$ increases, then $U_{k1\_after}$ also increases
6. If $v_1$ becomes twice as great, then $U_{k1\_after}$ becomes twice as great
7. If $v_1$ becomes twice as great, then $U_{k1\_after}$ becomes four times as great
8. None of the above is correct.
Feedback generation

- Student receives an assignment
- Student selects a hypothesis:
  - "a greater mass $m_1$ has no influence on the velocity after the collision"
- Student performs experiments
- Student decides if hypothesis is supported
- System generates feedback
  - selects relevant experiments
  - predicts values dependent variables from the hypothesis
  - compares predicted values with actual values
  - composes feedback
**Feedback on statement and experiments**

You claim that the statement *"If m1 becomes 4 times as big than the velocity after the collision becomes twice as big"* is true.

Below you find your experiments that are relevant for testing this statement:

<table>
<thead>
<tr>
<th>v1</th>
<th>v2</th>
<th>m1</th>
<th>m2</th>
<th>v1 after collision</th>
<th>v2 after collision</th>
<th>prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>-0.67</td>
<td>-1.25</td>
<td>-1.33</td>
</tr>
<tr>
<td>-2</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>-1.33</td>
<td>-2.66</td>
<td>-1.33</td>
</tr>
<tr>
<td>-2</td>
<td>0</td>
<td>0.5</td>
<td>1</td>
<td>-0.67</td>
<td>-1.25</td>
<td>-1.33</td>
</tr>
<tr>
<td>-2</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>-1.25</td>
<td>-2.50</td>
<td>-1.33</td>
</tr>
<tr>
<td>-2</td>
<td>0</td>
<td>8</td>
<td>1.0</td>
<td>-1.70</td>
<td>-2.87</td>
<td>-2.67</td>
</tr>
<tr>
<td>-2</td>
<td>0</td>
<td>1</td>
<td>1.0</td>
<td>-1.6</td>
<td>-3.2</td>
<td>-2.67</td>
</tr>
</tbody>
</table>

If all the values observed should match the values that you would expect based on the statement. This is however not the case. *This means there is reason to believe that this statement is not true.*
Outcomes of a study

Standard feedback
- Knowledge gain
- More assignments

Adaptive feedback
- Knowledge gain
- More time on an assignment
- More experiments for an assignment
- More relevant experiments
- More unique experiments

Veermans et al. IJSE (in press)
Scaffolds and collaboration

What was done?
Which variables?
Which hypothesis?
Which variables?
Which values?
What results?
Which conclusion?

What next?
Which variables?
Which hypothesis?
Which variables?
Which values?
What results?
Which conclusion?
Collaborative discovery

- Differences in opinion should lead to discussion and progress in learning

- Conversation of homogeneous dyads focused on orientation processes

- Heterogeneous dyads made more utterances related to hypothesis generation

Gijlers & de Jong, JRST (2005)
Supporting collaborative discovery

- Domain Kinematics (velocity, acceleration etc.)
- SimQuest simulation
- Three conditions
  - Shared hypothesis scratchpad
  - Shared proposition table
  - Control - Without scaffolds
- 66 students (± 15 years old)
Hypothesis scratchpad

<table>
<thead>
<tr>
<th>If</th>
<th>m_total</th>
<th>increases</th>
</tr>
</thead>
<tbody>
<tr>
<td>then</td>
<td>vt</td>
<td>decreases</td>
</tr>
<tr>
<td>if also</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If m_total increases, then vt decreases

<table>
<thead>
<tr>
<th>Proposition</th>
<th>true</th>
<th>Proposition needs testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remove</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>proposition</th>
<th>answer</th>
<th>test</th>
</tr>
</thead>
<tbody>
<tr>
<td>If m_total increases, then vt decreases</td>
<td>true</td>
<td>untested</td>
</tr>
<tr>
<td>If F_drive decreases fast, then vt decreases</td>
<td>true</td>
<td>tested</td>
</tr>
</tbody>
</table>
Larger (smaller) velocity means larger (smaller) acceleration.

1. This proposition is
   - Familiar
   - Unfamiliar

2. This proposition is
   - True
   - Probably true
   - Probably false
   - False

3. This proposition is
   - Worthwhile testing
   - Not worthwhile testing
### Proposition List

<table>
<thead>
<tr>
<th>Proposition</th>
<th>Jonathan</th>
<th>test</th>
<th>Marie-Anne</th>
<th>test</th>
</tr>
</thead>
<tbody>
<tr>
<td>An object with a constant net force will have a constant speed</td>
<td><strong>Probably true</strong></td>
<td></td>
<td><strong>Probably false</strong></td>
<td></td>
</tr>
<tr>
<td>If velocity equals zero, acceleration equals zero too</td>
<td><strong>False</strong></td>
<td></td>
<td><strong>False</strong></td>
<td></td>
</tr>
<tr>
<td>If the net force of an object doubles, the velocity of this object will also</td>
<td><strong>False</strong></td>
<td></td>
<td><strong>True</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Truth-value**: Unknown

**Experiment**: Force & Mass

- [ ] I want to test this proposition

**Start relevant experiment**
Results

- Shared proposition table condition significantly higher learning gains than hypothesis scratchpad
- Shared proposition table condition discussed significantly more unique propositions
- Students working with the shared proposition table explored a larger proportion of the simulated domain
Shared Proposition Table

- **Pro**
  - Helped students maintain a common focus
  - Externalized prior knowledge and ideas
  - Triggered the discussion about propositions

- **Con**
  - Students tend to focus on cases of disagreement
  - Students treat propositions as isolated statements
Concept mapping tool

- Students create a shared overall representation of the domain

- Requires students to:
  - Identify key concepts
  - Logically structure the concepts
  - Link concepts
Concept mapping tool

Linking lines
Experiment

- Domain Kinematics
- Simquest simulation

**Conditions**
- Proposition table
- Proposition table + concept mapping tool

- Subjects: 24 (around 15 years old)
Results

- Students in both groups improved on knowledge tests

- Students in the concept mapping condition reached significantly higher learning gains than the proposition table only

- In the proposition table only, more experiments were conducted but in the concept mapping condition there was more discussion per experiment

- Students did not use the concept mapping tool as a support for the simulation, but used the simulation to work on the concept map
When is inquiry learning effective?

- When the right type of domains is used (conceptual instead of operational)
- When relevant cognitive processes are triggered and scaffolded (either by the system or by a co-learner or by both)
- When the appropriate (prior) knowledge is available (either with the (co-)learner or in the system)
- When learners have a goal to work to (e.g., a hypothesis, a model, or a concept map)
Where does intelligence come in?

- We could use more adaptive scaffolding:
  - this means adapting it to the characteristics of students and
  - adapting it over time (fading)

- So, we need some kind of learner model
  - Unpredictable process
    - Pattern identification
  - Unpredictable product
    - Assessing the model that is built by learners
Our research agenda

- The role of “products” to design
  - Models (qualitative and quantitative)
  - Concept maps
  - Assignments

- The role of representations
  - Affordances of different types of representations (textual, arithmetical, graphical)
  - Multiple representations

- Collaboration and inquiry
  - Interaction between task related activities and communicative activities

- Process analysis
  - Interaction data
  - Assessment of models
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