Modeling peer effects in interactive learning

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Background & Significance

• Much of human learning occurs through interaction with
  – The task environment and
  – Other learners (including experts)

• Knowledge is
  – distributed in the world and in other minds
    • Learners tap into the richness and diversity of knowledge through interaction
  – incomplete, erroneous, or biased
    • Learners must verify, validate, and filter the knowledge gathered from others

• Learning through interaction with other learners
  – has the potential to enhance our collective intelligence (Malone, 2018)
  – Collective intelligence predicts twice as much variance as individual intelligence
    • in complex criteria (Woolley, Chabris, Pentland, Hashmi, & Malone, 2010).
Evidence from field studies

Active learning pedagogies
- interaction among learners
- learner centeredness
- improved learning outcomes.

Field studies, quasi-experiments:
- not replicable
- confounders

Controlled lab experiments:
- establish causality
- understand mechanisms

Computational modeling:
- generalization
- theory building
- applications

PAL study

• Goal:
  – understanding the mechanisms and outcomes of peer-assisted learning (PAL)

• Task: Paired-associate learning (PAL)
  – Stimuli: 60 word-number pairs

• Key contrasts:
  • Individual vs. peer-assisted learning
  • Passive vs. active learning
Design: between-subjects conditions

<table>
<thead>
<tr>
<th>Peer-Assisted Learning (PAL)</th>
<th>Individual Interactive Learning</th>
<th>Passive Learning</th>
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</thead>
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[Diagram showing the three types of learning: Peer-Assisted Learning (PAL), Individual Interactive Learning, and Passive Learning.]
### Design & procedure

- **Within subjects**

<table>
<thead>
<tr>
<th>HT</th>
<th>ST</th>
<th>HT</th>
<th>ST</th>
<th>...</th>
<th>HT</th>
<th>ST</th>
<th>Break</th>
<th>Final Exam</th>
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### School time procedure

<table>
<thead>
<tr>
<th>Condition</th>
<th>Word</th>
<th>Number</th>
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<tbody>
<tr>
<td>Passive Learning Condition</td>
<td>Word</td>
<td>Number</td>
</tr>
<tr>
<td>Individual Learning Condition</td>
<td>Word</td>
<td>Response (Number)</td>
</tr>
<tr>
<td>Peer-assisted Learning Condition</td>
<td>Word</td>
<td>Response (Number)</td>
</tr>
</tbody>
</table>
Hypotheses

• Active learning > passive learning
• PAL > Individual interactive learning
  – At test (session 7)
• Group performance > Individual performance
• Effort (amount of home time practice) would be lower in PAL condition
  – Social loafing effect
• Peer inspection data would be informative
ACT-R model predictions

Mean final session accuracy per conditions

Mean accuracy

Condition

TBL

AL

PL
PAL Process model diagram

1. **Read and encode stimulus (word)**
2. **Attempt to retrieve word-number pair (associate)**
3. **Associate retrieved?**
   - Yes: **Retrieved associate is reinforced in memory**
   - No: **Generate response**
4. **Random answer (guess)**
5. **Required to respond?**
6. **Read correct response (number)**
7. **Look at peer’s answer?**
   - Yes: **Look at peer response and reinforce associate in memory**
   - No: **Select peer to look at based on peer reputation / trustworthiness**
8. **Look at peer response and reinforce associate in memory**
   - Yes: **Trigger positive reward signal and learn peer trust**
   - No: **Trigger negative reward and learn peer distrust**
9. **Generate second response**
10. **Associate the correct response to the stimulus and reinforce the associate in memory**
In the learning sessions (1 to 6), accuracy in the PAL condition is not higher than in the IL condition.

In the testing session (7), accuracy is lower in the PAL condition than the IL condition.

The group answer is more accurate than the individual answer.

This effect could be a wisdom-of-crowds effect, a knowledge-spillover effect, or both.
This is a direct test of a peer effect.

A 1-unit increase in peer accuracy causes a quarter-unit (0.25) increase in learner accuracy.

Interacting with a knowledgeable peer in the previous session causes improved accuracy in the current session (and vice versa).

Even though the effect size is small ($r = 0.20$), this indicates a significant peer effect.
Taking a peer’s answer occurs quite frequently, even though it slightly decreases with learning (black line).

Taking a peer’s answer generally occurs when learner accuracy is low, though increasing (red line).

In general, learners become increasingly able to recognize accurate responses in their peers and take them (green line).

However, sometimes they take inaccurate responses from their peers.
The participants in the PAL condition did not study less at home. Thus, social loafing cannot explain their poor performance at test.

In fact, they studied significantly MORE than the other conditions.

Home time practice is correlated with test performance, particularly in the PAL condition, $r(134) = 0.68$.

Why does this effect not lead to better test performance?
In the PAL condition, learners are exposed to roughly as many incorrect responses as correct ones. Even though they are able to distinguish the correct ones during the learning sessions, the incorrect associates may persist in memory and interfere with the retrieval of correct responses at test. Thus, the positive peer effect might be offset by a negative interference effect.
The number of non-answers vary widely between conditions; it is 5% in the PAL condition and 0.3% in the individual interactive learning condition.

Non-answers predict poor test performance, suggesting that workload explains part of the poorer performance in the PAL condition.

When non-answers are included as a covariate, the difference between the two conditions becomes non-significant.
Summary of findings

• Positive peer effect via
  – Knowledge spillover among peers
  – Increased willingness to practice in the PAL condition

• Negative peer effect via
  – Exposure to incorrect responses
  – Increased workload in the PAL condition
How to model these effects?

• Minor refinements of the current ACT-R model can handle:
  – Increased workload in the PAL condition
  – Knowledge spillover among peers
  – Exposure to incorrect responses
  – Learning peer trustworthiness

• New mechanism needed to account for:
  – Increased willingness to practice in the PAL condition
Sketch of PROCESS MODEL for motivation channel

Select level of effort (amount of practice)

Required to respond?

Respond and get intrinsic reward

Read correct response and get extrinsic reward

Peers can see your answer?

Form sophisticated beliefs about peers (e.g., estimate level of effort)

Adjust own level of effort to coordinate with peers

Coordination equilibrium?

Get positive social reward

Get negative social reward
Work in progress

• Series of studies on knowledge-based reasoning and problem solving
  – Focus on interactive learning
• RAT-PAL study (remote associates test)
  – Search through a large knowledge base (KB)
  – Similarities, occurrences, and co-occurrences
• MAT-PAL study (Miller analogies test)
  – Search through a structured KB (ontology)
  – Understanding / mapping relational structures
  – Finding relationships between relationships
Conclusions and implications

• Clear evidence of positive peer effects
  – Via knowledge and motivation channels
• Emergent effects of combining multiple (natural and artificial) minds into super-minds (Malone, 2018)
• PAL may be particularly useful in knowledge-intensive tasks that require large amounts of knowledge and structured KBs (ontologies)
• Evidence of negative peer effects
  – Via error interference and workload
• Modeling challenges that need to be addressed:
  – Forming sophisticated beliefs about others and reasoning on them.
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