The role of interface style in planning during problem solving

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Abstract

It is argued that support from an interface during problem solving can make interaction easier. Interfaces often display relevant information, making recall unnecessary and relieving working memory, called externalization. However, externalizing information might not necessarily instigate planning, understanding and knowledge acquisition from the user. In previous studies, the effects of externalizing information in an interface not always converged. We describe an experiment investigating the influences of (1) inducement to plan and (2) externalizing information on problem solving. Contrary to others' findings, no advantages of externalization were found. Instead, *NOT* externalizing (requiring internalization) yielded advantages and facilitated planning from the user.

Keywords: Interface; knowledge acquisition; screen representation; planning; problem solving; externalization

Introduction

Many cognitive tasks are computer-based nowadays. We explore multimedia environments, and use computers in education, entertainment, office tasks and many other domains. Computer interfaces are often complex, and applications can have hundreds of functions. Designing the right computer interface for the right task can be tricky and this gave rise to a whole domain of human computer interaction research. "Usability" became a buzzword. One notion that came from usability studies is the importance of "minimizing user memory load", and a common recommendation is that users should interact on basis of recognition rather than recall. In practice this means that information, e.g., text, objects, actions and options should be made available only when a user could need them for a task, while hiding non-relevant information: *externalization* of information. By externalization we mean providing relevant information on the interface, making recall of certain knowledge unnecessary, thus relieving working memory. On the contrary, when information is not externalized, certain task information is less directly available and needs to be *internalized*, i.e. inferred and stored in memory before it can be used. If this occurs, an already constructed plan is available for subsequent use. There are many different types of information that can be externalized. As examples, think of interfaces that "take the user by the hand" by limiting choices and providing feedback (e.g. Van Oostendorp & De Mul, 1999), such as greying-out menu items that cannot be used in a particular context, thus offering a context-sensitive interface with just "possible" actions. This type of externalization prevents errors and limits search. For example in Word, one cannot select "paste" from the "edit"-menu, when nothing is copied or cut first. "Paste" is shown in grey, indicating that the command exists, but you cannot now use it. Wizards externalize the solution path. Help-options externalize the fact that extra information on a topic is available. That externalization is considered helpful is reflected in various GUI-guidelines, e.g., "visibility status", "feedback", "grey out inapplicable items", "provide help-functions".

But is externalization always helpful? When looking more specifically at certain problem solving tasks, planning and learning are thought to be essential factors. One could argue that during computer-based problem solving, externalizing all information can lead to "experiential cognition" (Norman, 1993): users are not triggered to look for underlying rules, form plans, or learn. In contrast, externalizing less information may trigger a user to engage in "reflective cognition", i.e. to plan and learn more actively.

This paper focuses mainly on the users' behavior that two interface styles (externalization and internalization) provoke, and specifically on the amount of planning and reasoning from the user's side.

In literature, traditionally the role of external representations has been underestimated. The pioneering work of Gibson (1979) has stimulated better analysis of the interaction between internal and external representations. Norman (1988) proposed the idea that knowledge might be as much in the world as it is in the head. He pointed out that the information embedded in technological artifacts (such as interfaces) was as important to task achievement as the knowledge residing in the mind of the individual who used that artifact. Norman argued that well-designed artifacts that externalized information as to their functions could reduce users' memory load, while badly designed artifacts increased the knowledge demands made on the user. The message stemming from this distinction drew attention to the implications that design decisions could have. Larkin (1989), for instance, considered the role played by differences in external displays in cognitive problem-solving, finding that externalizing information, enabling 'display based problem solving', helped people recover from interruptions in work. Note that Larkin's most revealing display externalized all the pieces of the solution path that had been accomplished, enabling a quick pick-up after a within-trial interruption. Tabachneck-Schijf, Leonardo and Simon (1997) created a model in which small individual pieces from different representations were linked on a sequential and temporary basis to form a reasoning and inferencing chain, using visually encoded information recalled to the Mind's Eye from long-term memory and cues recognized on an external display. They stressed that much reasoning could not take place without external information being present – exactly what was found in a study by Mayes, Draper, McGregor and Oatley (1988). More recently, there has been more research on internalization and externalization in problem solving, most requiring planning. Assuming that by externalizing certain information, working memory is relieved, Zhang and Norman (1994), Zhang (1997), like Larkin (1989), showed that externalizing information can be useful for cognitive tasks: the more is externalized, the easier it is to solve a problem. Zhang externalized the rules of the problem, which prevents errors and relieves working memory but does not alter the problem space. Redistributing information from the internal memory to an external display helps. O'Hara and Payne (1999) and Trudel and Payne (1996), on the other hand, stated that too strong a reliance on external information leads to negative effects regarding planning and transfer of skills. They drew a distinction between plan-based and display-based problem solving. In plan-based problem solving one uses detailed problem strategies from long-term memory, leading to shorter solutions. Display-based makes little use of learned knowledge but relies on interface information, usually involving more steps because of more searching. O'Hara and Payne also found that making an interface harder to use by imposing delays on operators (thus making them more costly), makes subjects plan more. Also, the higher the cost of error recovery, the more planning subjects displayed. A similar observation was made by Svendsen (1991). Using the Towers of Hanoi problem, a high-cost interface yielded improved understanding of problems.

Externally available information, thus, is not *always* beneficial. Payne, Howes and Reader (2001), for instance, regard the principle that artifacts and representations should be designed to maximize the potential for cognitive offloading as a mistaken over-generalization.

Research by Van Nimwegen, Van Oostendorp and Tabachneck-Schijf (2004) surprisingly showed *no* performance advantage for externalization over internalization. Subjects were presented with two versions (internalization or externalization) of an isomorph of the well-known "Missionaries & Cannibals" puzzle, which we called Balls & Boxes (B&B). The puzzle had a set of underlying rules, certain types of moves were "illegal". To reach the solution a certain strategy is required, always obeying the rules. These rules were enforced by not allowing certain moves to be performed. In the externalized condition, the interface showed which moves were *allowed*. If a move in the puzzle would lead to an illegal situation (violating a rule), this was externalized by means of disabling certain controls. Thus subjects could only perform legal moves. However, it has to be bared in mind that NOT the solution path itself was externalized. In the *internalization* condition, subjects had no clue whatsoever about the legality of moves. They had to find out everything by themselves. Subjects solved a series of problems; performance was measured as well as their knowledge of the problem's rules and states afterwards. Unexpectedly, the time needed, and correctness were the same in the two conditions. However, *internalization* yielded better knowledge of the rules afterwards. Internalization subjects also showed more planful behavior by avoiding dead-end problem-states far better. Furthermore, this better knowledge was still evidenced eight months later in a re-run of the experiment. In other words, not at any moment did externalization yield advantages, only internalization did. This in itself might be not so strange, since there is ample evidence that discovering something yourself can facilitate learning (Carroll, 1990). Requiring information to be internalized rather than externalizing it imposes a cost on the user, aligning these results with those of Payne and colleagues. Our results indicated that when not all information is externalized, the solver is triggered to start figuring out the problem on a more metacognitive level, planning more, and remembering more about move sequences and rules.

The indication that requiring internalization encourages planning and learning, led us to conduct another experiment to investigate the interaction of planning and externalization. What will be subjects' behavior if they are not just confronted with one of the two interface styles, but also explicitly asked to plan moves carefully, vs. to shallowly solve the tasks? We hypothesized that in with externalization, explicit instruction to plan might not make a significant difference, because the interface would preclude planning. In the internalization condition however, where we saw subjects planning more, we expect users' planning to be facilitated when instructed to plan carefully. On the other hand, with internalization, when subjects are instructed to solve shallowly, it might inhibit planning and learning.

Method

Subjects and Design

Thirty-two subjects, aged 19-35 were randomly assigned to four conditions, eight per condition. They were undergraduate students from Utrecht University and received a 5 € reward afterwards. Our 2x2x3 design has two between-subject independent variables: interface style (internalization or externalization) and planning instruction (low or high) and one within-subject independent variable, puzzle version (6, 8, or 10 balls). Among the dependent variables were:

1. Performance measures (all logged by the computer)
    - correctness: the number of correctly solved puzzles
    - speed: time needed to solve the puzzles
    - extra moves: the deviations from the shortest path
    - the number of illegal moves
2. Knowledge test

After the trials we measured how well subjects had learned the rules and shortest-path solutions of the problem.

3. Attitudes

Likert-scale questions concerning, among others, perceived amount of planning, feeling lost during interaction.

Material

The experiment was conducted in the usability lab at the Center for Content and Knowledge Engineering, Utrecht University. The java-applet ran on a Pentium 4 PC with a mouse, keyboard, and a 17" monitor, and logged virtually everything subjects did: mouse clicks, timestamps, path measures, types of (attempted) illegal moves made etc.

The puzzle

As in earlier experiments, we used our Balls & Boxes application. It is informationally equivalent to "Missionaries and Cannibals". 5 missionaries and 5 cannibals stand on a river-bank, and all have to reach the other bank by boat. The boat only holds 3 people; the minimum to sail is 1. If cannibals ever outnumber missionaries at any place, the latter will be eaten. At one point a contra-means-end-analysis move has to be made, this bottleneck is passed after a minimum of 7 moves (fig. 1, black square). The B&B problems (fig. 2) use the same problem space, but are more abstract (Missionaries and Cannibals-rules contain a lot of common cultural knowledge: cannibals eat people, boats cross rivers). With boxes, colored balls and a dish instead, we avoided too easily learned rules. The rules translate to:

1. Balls should be transported using the dish
2. You can transport at most 3 balls at a time
3. To move, the dish must contain at least 1 ball
4. The dish has to reach the boxes in turn
5. No more blue than yellow balls in the dish
6. No more blue than yellow balls left in the boxes

Below is the formal problem space of the puzzle. The shortest path to solve it is 11 moves, but one can wander around the problem space. There are several "dead-end-states" (circled in fig.1) that force back-tracking.

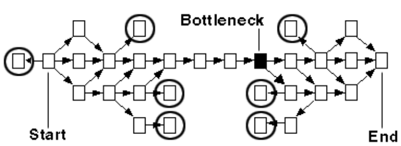

Figure 1: The Balls & Boxes problem space (B&B5)

Unlike in earlier experiments, we decided to let the puzzle change a little over time. The number of balls in the game gradually increased. The solution basically is the same, but more balls make it *look* more difficult. Only one rule (maximum balls in dish) varied. We constructed 3 puzzles:

B&B3: 3 blue /3 yellow balls. Solution 11 dish-moves
B&B4: 4 blue /4 yellow balls. Solution 9 dish-moves
B&B5: 5 blue /5 yellow balls. Solution 11 dish-moves

From earlier experience we knew that subjects' performance did not improve much more after 2-3 trials, so we decided to keep the numbers of puzzles to be solved low. All subjects had to solve "B&B3" 3 times, and "B&B4" and "B&B5" both 2 times, 7 puzzles in total. The controls were simple: to get blue/yellow balls into the dish, blue/yellow up-arrows had to be clicked and to move the pink dish horizontally; one had to click a pink arrow (left or right). The independent variable "interface style" (internalization vs. externalization) was operationalized as follows.

1. Externalization: Arrows are only colored (clickable) when an action is legal and greyed out (unclickable) if illegal. E.g. moving the dish empty in figure 3 is illegal because it violates rule 3. In this situation, this rule is externalized by greying out both pink arrows. Note that this type of externalization, like in Zhang's (1997) experiments, errors are prevented and working memory is relieved because rules do not need to be learned, but the problem space is not altered.

2. Internalization: All arrows are always colored providing no information about the legality of moves. One can click all buttons at all times. However, an illegal move is not executed. For instance, if one wants to move the dish empty and clicks a pink arrow, nothing happens.

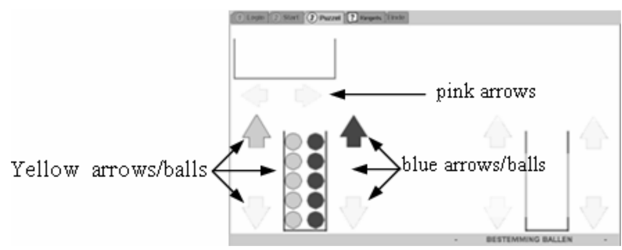

Figure 2: The externalized version of B&B5

Procedure and Instruction

Subjects received a general instruction on the course of the experiment, starting with a screenshot and the phrase "*All balls should be transported from one side to the other. However, there are constraints, not everything is allowed. Find out for yourself how it works*." After this, our independent variable "planning instruction" was applied:

1. Low planning instruction: *"Try to solve the puzzle as fast as possible, making mistakes is not a problem. Good luck!"*
2. High planning instruction: *"Try to solve the puzzle as economically as possible. Think hard, plan with care, it pays off. Good luck!"*

Subjects solved 7 trials (3xB&B3, 2xB&B4, 2xB&B5, about half an hour). After completing them, they were presented with the knowledge questionnaire (10-15 minutes).

Results

Solution Times and Correctness

On average, as we saw in earlier experimentation, the time that subjects needed to complete the puzzles was neither influenced by interface style, nor by planning instruction. The same was true for the correctness (the number of correctly solved trials out of 7 over the 3 puzzles).

Extra moves

The path measure we call "extra moves" is calculated by subtracting the shortest-path number of moves from the moves needed. For B&B3, B&B4 and B&B5, the shortest paths were respectively 11, 9 and 11 moves. To meaningfully compare the extra-moves scores per puzzle version, we standardized the "extra moves" to z-scores.

The within-subjects variable "puzzle version" showed no significant *main* effect. There was no significant 3-way interaction effect between puzzle version, interface style and planning instruction (F(2,54)=1.98, p=0.15). Also the interaction between puzzle version and planning instruction was not significant (although a bit stronger, F(2,54)=2.28, p=0.12).

The interaction between puzzle version and interface style on the scores for "extra moves" was significant at F(2,54)=3.23, p=0.05. Figures 3 and 4 show that in the *externalization* condition the scores are practically identical during the 3 puzzles (regardless of the planning instruction). However, the scores in the *internalization* condition look quite different.

In the *low* planning condition (fig. 3), a repeated measures ANOVA showed neither significant differences in extra moves for the puzzle versions, nor for interface style. However, this was different for the high planning condition (fig. 4). The patterns between the two interface styles are quite different, especially for B&B3. Repeated measures showed a significant interaction effect for puzzle planning instruction and interface style F(2,13)=6.31, p=0.01. Post hoc Tukey tests ($p < 0.05$) showed that in B&B3, internalization subjects (M = -1.05, SD= 0.39) needed significantly fewer extra moves than externalization subjects (M = 0.32, SD = 0.91). In puzzles B&B4 and B&B5 there were no significant differences between interface styles.

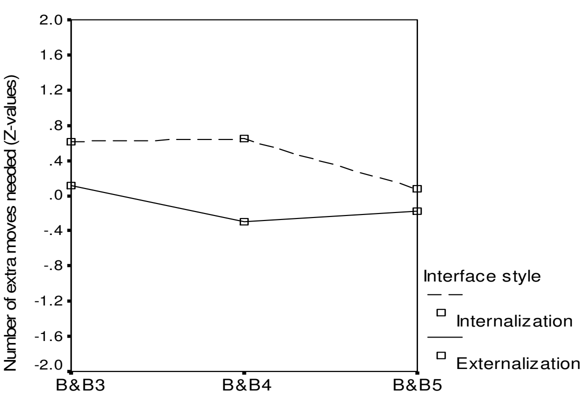

Figure 3: Extra moves per puzzle version in **low planning**

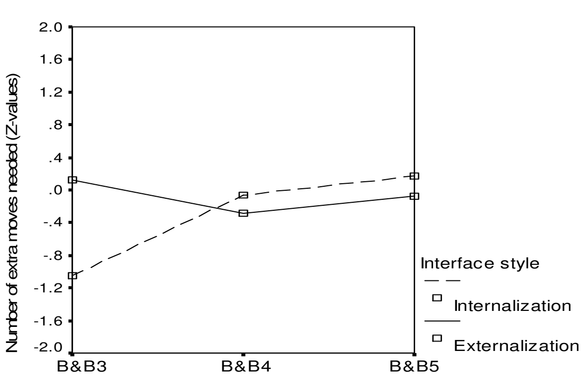

Figure 4: Extra moves per puzzle version in **high planning**

Furthermore, not regarding the puzzle version, there was a nearly significant interaction effect between interface style and planning instruction F(1,27)=3.17, p=0.08. Figure 5 shows that externalization, like in figures 3 and 4 was not influenced by planning instruction, but internalization was; this difference was significant t(14)=-1.94, p=0.03.

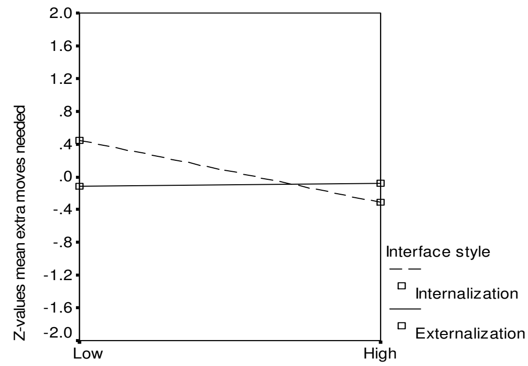

Figure 5: Average extra moves needed per interface style and planning instruction

Perceived amount of planning

Subjects also rated the amount of planning as perceived by them selves on a 5-point Likert scale. An ANOVA yielded just a tendency of an interaction of planning with interface style which did not reach significance, F(3,28)=2.24, p=0.14. However, the pattern fits earlier mentioned results quite well; only in the high planning instruction, interface style has an effect. In the high planning condition, subjects that worked with internalization (M = 3.38, SD = 0.92) felt that they planned more than subjects in the externalization condition (M = 2.38, SD = 1.06), t(14)=2.02, p=0.03.

Attempted illegal moves

Results so far point out that externalization subjects are not influenced by planning instruction, but internalization subjects are. Some variables were only measurable in the internalized interface, e.g. "attempted illegal moves". In the externalized version one could only make legal moves, while in the internalized version it was also allowed to attempt illegal ones, since the control arrows were always clickable. Within internalization we compared the number of times that this occurred, in relation to planning instruction.

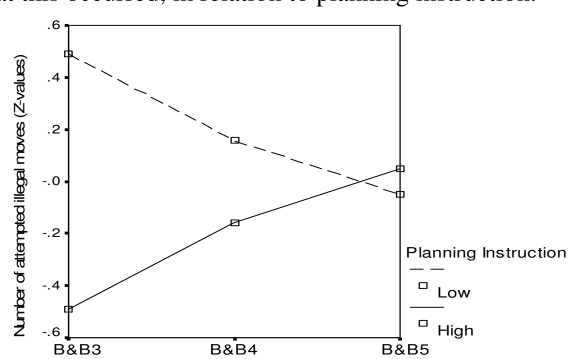

Figure 6: Number of attempted illegal moves by internalization subjects per puzzle-version

A repeated measures ANOVA showed an interaction effect $F(2,28)=4.27$, $p=0.03$ (fig. 6). In the internalization condition, in the first puzzle (B&B3) the high planning instruction ($M = 81.50$, $SD = 43.94$) resulted in much fewer illegal moves than low planning instruction ($M = 163.75$, $SD = 96.05$), $t(14)=2.20$, $p=0.02$. After B&B3 the effect was gone.

Knowledge

There were 3 questions concerning the crucial rules of the puzzle, the answer could be correct or incorrect (score range 0-3). An ANOVA showed, as in earlier experimentation that the knowledge of the rules afterwards was influenced by interface style, $F(1,28)=11.01$, $p=0.03$. Planning instruction had no influence. As before, the average knowledge acquired by internalization subjects ($M = 1.95$, $SD = 0.77$) was better than for externalization ($M = 1.0$, $SD = 0.82$).

Discussion and Conclusion

We analyzed the influences that interface style, (externalization or internalization) has on performance and knowledge acquisition in a problem solving task. According to Zhang (1997) and others, the more information is externalized, the easier a task becomes. We do not feel this to be true in all cases, e.g. when learning is required, when executing the task faster is the aim or when the task is prone to interruptions. The latter, we think depends on the timing of the interruption (between-trials or within-trial) and the amount of information remaining on the interface at the time of the interruption. Larkin's (1989) interruptions were within-trial, and in the externalized version all needed information remained visible. Our interruptions were between-trials and no information remained visible.

We hypothesize that removing error-making from the interface by externalizing the rules has a cost, namely a lessening of metacognitive activity such as planning, and consequently, less learning. In this paper, we therefore varied the planning instruction (low or high) subjects received. Subjects were either encouraged to do the task fast, errors did not matter (low planning) or to plan carefully and work as efficiently as possible (high planning).

O'Hara and Payne (1999) showed that making the interface slower makes subjects incur a cost for errors and extra moves, and induces planfulness, which in turn causes subjects to learn more. Does this hold also when we require subjects to internalize information as opposed to externalizing it? We hypothesized this to be the case, as requiring internalization is also costly.

Surprisingly, performance measures such as time needed to solve the puzzles and number of correctly solved puzzles were not influenced by the interface style. As in the previous study by Van Nimwegen et al. (2004), Zhang's (1997) prediction was not confirmed: externalization of the rules held no advantages. Also, the new condition *planning instruction* had no influence on the performance measures *correctness* or *solving time*. The latter was not exactly as we expected but we understood it better when we had analyzed the "extra moves".

"Extra moves" is a path measure we used as an indicator of planning by subjects. This measure focuses on *how* subjects solve the problem, not on *if* or *how fast*. It reflects the directness, the efficiency of the path that subjects chose. A small amount, or even better, no "wandering back and forth" at all around the problem space, is taken as indicator of planning and contemplation by subjects. The opposite would be just trying to solve the problem by trial and error, making many unnecessary extra moves. Concerning extra moves, internalization subjects were positively influenced by planning instruction and externalization subjects not at all. This effect was the largest in the first puzzle. Here, high-planning internalization subjects outperformed the three other groups by needing far fewer extra moves, thus displaying smarter, more thoughtful behavior. Their planful behavior was confirmed by the fact that there were no differences in solving time. Subjects acted more carefully and considered their moves more. It seems that being confronted with our type of externalized interface makes a subject ignore, or even forget the planning instruction all together. As externalization subjects were not confronted with actual mistakes (one could not make illegal moves, only inefficient legal moves were allowed), they simply kept on solving without applying meta-cognition (Tabachneck-Schijf, 1996). This idea of attention taken by an interface fits with Carroll and Rosson's (1987) paradox of the active user – users of computer systems are so consumed with immediate productivity that they are not motivated to take time to learn better ways of accomplishing their task.

These findings are confirmed by subjects' own judgments of their planning. Results pointed in the same direction; only subjects in the internalized interface with a high planning instruction reported having done a considerable amount of planning. The fact that subjects' own judgment of planning coincided with our extra-moves findings, indicates that "extra moves" is an adequate measure for planning.

Only the interface where subjects had to internalize the needed information, allowed attempts of illegal moves (besides the mentioned *legal* extra moves), since all controls were always clickable. The interface gave little information away about the rules of the puzzle, so of course subjects in the internalization condition attempted illegal moves at some point. Subjects with low planning instruction attempted twice as many illegal moves as the ones with high planning instruction. This reconfirms that in internalization, planning instruction has an influence, high-planning instruction facilitating and low-planning instruction inhibiting planning as compared to the externalization subjects.

After the tasks, the knowledge of subjects was tested, and proved to be influenced only by the interface style, as in earlier experiments. Although planning instruction in one condition resulted in fewer extra moves and higher perceived planning, it had no influence on how well the knowledge was remembered. We expected that high planning instruction *and* having to internalize information would reenforce each other, resulting in even better knowledge, but this proved not to be the case. Interface style alone still was the main convincing factor of influence. Perhaps the nature of the puzzle was such that all internalization subjects acquired the knowledge as good as it can be already, and that planning instruction (and consequently their behavior) therefore could not make a difference anymore.

Our results indicate that in the externalized condition, subjects were "deaf" to the planning instruction. It was the combination of interface style and planning instruction that was deciding in subject's behavior. Externalization seems to encourage trial and error problem solving, which stands opposite to planning. Relying on interface information in this manner, making little use of learned knowledge corresponds with display-based problem solving behavior as defined by O'Hara and Payne (1999).

Remarkable is again, that no advantages of externalization were found in either this or the previous experiment. It was internalization that yielded advantages. Firstly, internalization resulted in more solid knowledge, as found earlier. Secondly, in the internalization condition, the given instruction was actually obeyed (in externalization it was not). If in a given situation it is crucial or important that an instruction is followed, one might consider not using too much externalization.

When high planning instruction was given in internalization circumstances, it showed to have a positive influence: subjects displayed more planning and smarter behavior. As in O'Hara and Payne's (1999) article, an interface that is in some way "harder to use", allows more plan-based behavior. Planning instruction has a maximum effect if no help is supplied by the interface.

This research aims to contribute to theory on how knowledge organization, learning and memory relate to modern insights in computing and learnability, and to visualization of human-computer interaction. In future research we will investigate what happens if the planning instruction is being repeated, look at different levels of externalization and feedback, and perhaps adaptively derive how well subjects are doing, and re-provide subjects with planning instruction on the basis of that. The factors we also intend to research are interruption, differences in internal motivation, and changes in the interface environment, time pressure and rewards.

In addition, our puzzle task is not very realistic and results cannot be expected to generalize to realistic tasks. However, the advantage of our task is its tractability and the amount of control one can exercise over it. We plan to further investigate effects of externalization and planning in more realistic tasks, e.g. spreadsheet or drawing applications, where actions are less repetitive, more life-like, and more complex, and are currently designing such an environment). In sum, if learning or performing metacognitive activities is the objective (as in the educational software domain) then planning and engagement from a user are essential, and requiring the user to incur a cost may be necessary to achieve this.

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