Does an Interface with Less Assistance Provoke More Thoughtful Behavior?

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Christof van Nimwegen
Herre van Oostendorp
Utrecht University, Padualaan 14, 3584CH Utrecht, The Netherlands
christof@cs.uu.nl, herre@cs.uu.nl

Daniel Burgos
Rob Koper
Open University of the Netherlands, Valkenburgerweg 177, 6401DL, Heerlen, The Netherlands
daniel.burgos@ou.nl, rob.koper@ou.nl

Abstract: This paper investigates effects of interface style and cognitive style on problem solving performance. It is often assumed that performance improves when information is *externalized* onto the interface. Although relieving working memory this may discourage planning, understanding and knowledge acquisition. When information is *not externalized,* it must be *internalized,* stored in the user's memory, requiring more planning and thinking, perhaps leading to better performance and knowledge. Another variable influencing behavior is the cognitive style of users. We included "Need for Cognition" (NFC), the tendency to engage in cognitive tasks. We investigated the effects of interface style and NFC using planning tasks. The internalization interface led to more planful behavior and smarter solutions, but NFC had no effect. Understanding reactions to interface information is crucial in designing software aimed at education and learning. To facilitate active learning and provoke better performance, designers should take care in giving users (too) much assistance.

Introduction

Computers are indispensable in many working environments and multimedia are nowadays omnipresent in education, training and cultural institutions such as museums or science parks. A recurring issue in software design guidelines to assure some degree of usability is minimizing "user memory load", referred to as computational offloading (Scaife & Rogers, 1996). The working memory of a user has to be relieved so that a maximum of cognitive resources can be devoted to the task. *Externalization* of information, providing information on the interface to structure and guide problem-solving, often is thought to be a means by which user memory load can be minimized. The need to plan is reduced and externalization can limit the possibilities in a given situation, thus reducing the problem space (Zhang & Norman, 1994). A way to implement some degree of externalization is to make parts of the interface context-sensitive, e.g. by hiding or disabling inapplicable functions. The user is "taken by the hand" by limiting choices and providing feedback (Van Oostendorp & de Mul, 1999; De Mul & Van Oostendorp, 1996). This is related (but not equivalent) to the concept of scaffolding (Soloway, Guzdial & Hay, 1994), adopted in research on technological supports for learning. It refers to interface support to assist learners in mindfully participating in work that would otherwise be too complex. The difference is that scaffolding is meant to provide structure and guidance during learning a *new* task that a user cannot do alone. However, externalization as we use it here (and others), is *not* meant to specifically motivate mindful participation, but is rather supposed to free up cognitive resources to eventually smoothen task execution. Examples where externalization of information is applied are software installation wizards or grayed-out menu-items that don't permit using them thus offering a context-sensitive interface with only "possible" actions. For example, in Word you cannot select "paste" from the menu when nothing is copied first. "Paste" shown in gray color indicates its presence *and* its (temporary, situation dependent) unavailability. It informs users about the applicability of operators and makes remembering this unnecessary. Zhang and Norman (1994) found that relieving working memory by externalizing information could be useful for cognitive tasks: the more is externalized, the easier it is to solve the problem. But one could also argue that externalization may have negative consequences for task performance and knowledge acquisition. There is research in the context of externalization and feedback depicting current states of objects and changes of objects. For a discussion in the light of cognitive load theory (CLT) (Sweller, 1994) concerning the effects of different external visualizations on the acquisition of problem solving skill, see Scheiter, Gerjets and Catrambone (2006). They showed that use of certain animations (meant to explain) led to a substantial increase in learning time and a decrease in performance. The animations used to visualize solution procedures were more harmful than helpful for conveying problem-solving skills. They state that these visualizations may reduce learner activity and induce a passive style of processing. This could prevent learners from performing effortful cognitive processes required for understanding.

There is a general notion that learning is more effective when people experiment and discover for themselves and exploratory learning as a whole has been a subject of research in many domains. Carroll (1990) for example, already more than a decade ago propagated minimalism in design and instructions. When the design of a system is "incomplete" on purpose, users must explore the system actively, make guesses and learn from mistakes. Kerr and Payne (1994) pondered why active learning *with* the target system would be more effective than with reading instructions. Is it because the user is free to set his own goals, or to use their own words, "*is it that the learner has to attempt to solve problems himself, actively choosing or inferring the next command, rather than merely reading and applying potted solutions?"*. In their experiment different types of training for MS Excel were compared, using active (problem-solving) and passive (tutorial-like, prompted interaction) learning contexts. They found that in training versions where users had to actively perform problem-solving, already during training users had a clear learning advantage. One can imagine situations in which performing skills in the long term is more important than performing well immediately after training. Charney and Reder (1986) found that a condition that provided added difficulty for learners (problem-solving) resulted in poorer initial performance than other conditions (e.g. "guided practice"), but to better delayed performance. An explanation could be that the more difficult condition perhaps instigates a deeper level of cognitive processing which eventually results in more effective learning.

What will be the influence of externalization on learning? Perhaps knowledge gained using an externalization-based interface is more volatile and difficult to transfer to other situations. This is undesirable when learning or gaining insight *itself* is the aim or when making errors is costly. Payne, Howes and Reader (2001) state that when information is externalized on the screen, users are reluctant to store relevant information in memory and are more inclined to use the external representation. O'Hara and Payne (1998, 1999) showed that dependence on exploration-support may indeed have a negative effect. Having to internalize information on the other hand may lead to more planning, better task performance and more knowledge acquisition. They distinguished between plan-based and display-based problem solving. In plan-based problem solving one uses detailed problem strategies from long-term memory. Display-based problem solving makes little use of acquired knowledge but relies on interface information. Plan-based activity leads to shorter solution routes, because steps are planned, and no unnecessary steps are taken, while a display-based strategy involves more steps because of more searching. Plan-based behavior was provoked by varying the operator cost in the interface of a puzzle, which existed in a low-cost interface and a high-cost interface. The latter imposed a longer lockout time (system response time) on subjects than the low-cost interface after an action, which made the system harder to use. The high-cost interface induced a plan-based approach which led to better performance, and the task knowledge acquired was more easily transferred to problems within the same domain. From a CLT point of view (Sweller, 1994), provoking plan based behavior is comparable with increasing "*germane load*". It refers to the degree of effort involved in processing and construction schemas, and is associated with motivation and interest. In CLT, *extraneous* load should be minimized. Extraneous load takes up valuable working memory resources away from the task and could be compared with effects of "externalization".

The design of problem-solving environments should *not discourage* planning. Strong reliance on the visual display may result in less transfer of skills and less planning. Externalizing information may not be beneficial when the goal is to achieve better, transferable task performance and knowledge. Besides better transfer to other situations, one could imagine that possessing better internal knowledge-elements, leads to better performance when one has worked with the application some longer time ago. Van Nimwegen, van Oostendorp and Tabachneck-Schijf (2004) studied this using an abstract version of the "Missionaries and Cannibals" puzzle. They investigated effects of internalization vs. externalization on task performance, knowledge, and transfer to a different problem in the same domain. The puzzle, called Balls & Boxes existed in two interface styles: externalization and internalization. Externalization was realized by graying out inapplicable (momentarily unavailable) buttons needed to perform certain operations. In the internalization condition this support was absent. To their surprise, not ever and not on any measure did externalization subjects perform better. Moreover, internalization subjects had better *knowledge* afterwards, and 8 months later the internalization subjects *still* had better knowledge and now also better performance. In addition these subjects performed better at transferring acquired rule-knowledge to a different but similar task. In a follow up study Van Nimwegen et al. (2005) investigated whether possible *differences in attitude* to problem solving were of influence. Besides interface style it was tried to influence task conception or attitude by giving instructions encouraging plan-based behavior in one group and encouraging display-based behavior in the other group. They used specific instructions to change the affective state of a user. It could be either a low-planning instruction ("solve as fast as possible, mistakes are not a problem") or a high-planning instruction ("solve as economically as possible, it will pay off"). Again internalization subjects performed better and had better knowledge. The instructions had no effect on externalization subjects: there was no difference in behavior between subjects that received high-planning vs. low-planning instructions. Upon being confronted with the externalization interface, subjects ignored or even forgot the planning instruction altogether. However, instructions *did* have effect on *internalization* subjects. With a low-planning instruction, they made twice as many illegal moves and more unnecessary moves, as compared to those with high-planning instruction.

The Current Research Problem

A drawback from the tasks used in the experiments above is that findings may not be relevant in realistic tasks. We argue that in problem-solving situations where people need to learn the underlying rules of a system, or make as little mistakes as possible, the use of a plan-based approach is preferred. If a using plan-based approach is preferred, as can be the case in learning situations, we should find out how people can be persuaded into using that approach. We will again investigate our assumptions, but now with a more realistic, more life-like task.

Interface Style

We will investigate the influence of interface style on performance on a problem-solving task. We define the externalization of the underlying rules as visualizing the result of *applying a set of constraints* onto the interface. Externalization shows which actions are allowed, comparable to grayed out menu items in for example Word, where it is shown that the current situation does not permit a function to be used because the constraints are not met.

Cognitive Style

We included subjects' differences in attitude to problem solving, because it could have an influence on behavior and performance. We used "need for cognition" (NFC), a psychological construct that measures the tendency of individuals to engage in and enjoy effortful cognitive tasks (Cacioppo, Petty & Kao, 1984). Both persons high and low on NFC need to make sense of their world, but tend to do this in different ways. A person with a high NFC loves to seek, reflect on and reason about information, whereas someone on the other end of the continuum only thinks as hard as (s)he has to and is inclined to rely on others. Crystal and Kalyanaraman (2005) demonstrated that NFC can influence perceived system usability and responses, or as they put it: "*If, in a particular HCI context, individuals high in NFC exhibit significantly different behavior than individuals low in NFC, usability could likely be improved by providing interfaces optimized for each group.*" Also other literature on adaptation and learning systems emphasizes the importance of adapting the external representation to the emotional state of learners (Kort, Reilly and Picard, 2001), or proposes adapting to various constant and volatile user characteristics (Brusilovsky, 2001). In this context, this could perhaps mean that a person with a high NFC in the externalization condition might still exercise a high amount of planning, as opposed to a low NFC subject, who is reluctant to plan.

Hypotheses

H1: Internalization leads to a more plan-based strategy and better performance than externalization. Externalization, providing assistance, tempts users not to form plans, but to rely on the interface. The internalized condition lacks this guidance and encourages planning. This planning involves spending effort on activities such as studying relevant elements of the situation, and construction and application of strategies based on elements retrieved from memory. We expect that requiring internalization will lead to better task performance and knowledge.

H2: High NFC leads to a more plan-based strategy than low NFC. People with high NFC have high intrinsic motivation to think and engage in cognitive tasks, will show more plan-based behavior. Consequently, we expect the subjects with a high NFC to have better task performance and knowledge.

Method

DESIGN AND SUBJECTS

The experiment had a 2X2 design with two independent variables: interface style (internalization or externalization) and cognitive style (low or high NFC, based on median). 43 university students (aged 19 to 32 years) participated, and received a five € reward. The experiment took an hour at most.

Material

NFC questionnaire

We used a Dutch translation of the 18-item NFC scale (Cacioppo, Petty & Kao, 1984). Subjects rated each statement (e.g. “Learning new ways to think doesn't excite me very much”) on a Likert-scale ranging from one to seven. A score of one meant ‘strongly disagree’ and a score of seven meant ‘strongly agree’. We averaged the scores on the 18 items, and split the groups on the basis of the median in “low-NFC” and “high-NFC” groups.

The Conference Planner Application

A software application called “Conference Planner” was developed by The Open University of The Netherlands and funded by the European UNFOLD Project. It simulated the planning of speakers for a conference, and consists of different components. The first one is the dynamic interface that shows every set of demands for a conference and allows the user to solve the problem based on drag & drop movements. The second one is the core of the application, the set of rules and related algorithms. Here the permitted actions and subsequent consequences are defined. The third one is the set of tasks with all the scenarios (there were 5 different scheduling situations). The conference speakers (each with different demands) had to be scheduled in one of three rooms (each with its own facilities and availability). The tasks are not difficult, but a certain approach is necessary to solve the situation in an economic manner. Without planning, the scheduling will not be optimal and extra (superfluous) moves are necessary. An adequate strategy is to look for speakers with many constraints and schedule them first. It can also be effective to first identify slots that are hard to fill and then assign speakers to those. Less smart would be to start from the top and work your way down, because at some point remaining speakers cannot be placed anymore and speakers have to be moved around. The latter strategy and also approaches such as “trial and error” do not involve much planning. The list of speakers with their constraints was shown on the left. The task was to place all the speakers on the timetable. The difference between externalization and internalization was implemented by showing, in the externalization condition where speakers can be placed (see Figure 1). When clicking on a speaker, the “legal” time slots (satisfying the constraints and being available) turned green. It however does *not* show the *best* slot, only legal ones. To move a speaker from left to right an icon in front of the speaker’s name had to be “picked up” and “dragged” to its destination with the mouse. Some timeslots where always unavailable, indicated with light-gray. Empty available timeslots were white, and those occupied by a speaker would display the name of a speaker in it.

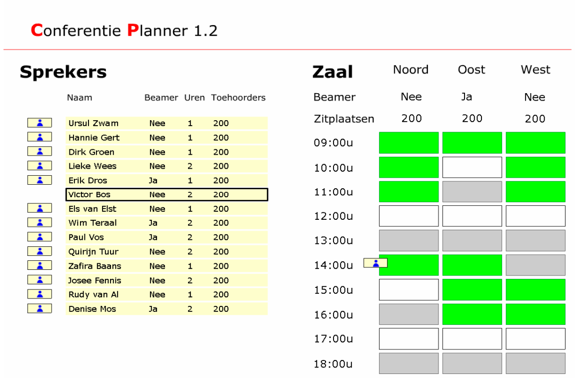

Figure 1. The externalization condition

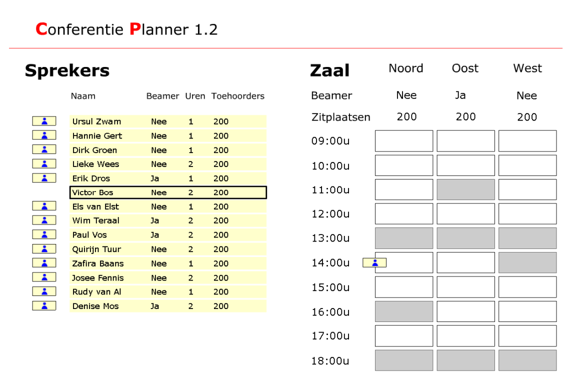

Figure 2. The internalization condition

In the internalization condition this feedback was absent (see Figure 2) and the legality of moves had to be inferred. A solution where each speaker was scheduled always existed. There were 5 tasks, with varying constraints:

- Amount of hours they will speak (1 or 2, in Dutch: uren)
- Whether a beamer* is needed (yes/no, in Dutch: ja/nee) (*Dutch/German pseudo-anglicism meaning “projector”)
- Number of expected listeners (in Dutch: toehoorders)

Our quantitative measures can be divided in time-based measures (durations of actions) and move-based measures (solution paths). All the sessions were captured, and for each of the 5 tasks we analyzed whether or not subjects started solving the problem with the best strategy (first moving the speakers with the most stringent constraints).

Post-experimental questionnaire

After the 5 tasks subjects completed a questionnaire assessing knowledge of the problem. We assessed *declarative knowledge* and *procedural knowledge*. Mostly the questions explicitly asked for explanations (“why?”), besides “yes” or “no”. A picture of a situation accompanied most of the questions.

- *Declarative knowledge*: Essay questions about situations that were either legal or illegal given the constraints. It had to be decided whether or not situations could occur, and why (or why not).
- *Procedural knowledge:* Essay questions concerning solution procedures. Parts of situations were given and the questions were formulated as "how would you do this?" and "is this a smart move?"

Procedure

The experiment was conducted in the Usability Lab of the Center for Content and Knowledge Engineering, Utrecht University. It started with the NFC questionnaire, followed by a textual introduction and a small video-clip showing how the application and its controls worked. After this, subjects started to work on the 5 problem solving tasks. Finally the electronic post-experimental questionnaire had to be completed.

Results

We analyzed the results using ANOVA ($p < 0.05$). All subjects eventually solved the 5 tasks correctly (see Table 1). The minimum and maximum average score on the NFC-scale were 2.39 and 6.50. The mean score was 4.89 (SD 0.83), with the median at 5.06. There were no interaction effects.

Time and moves

Table 1: Time (sec) and moves for each condition

	Internalization				Externalization			
Average for the 5 tasks	Low NFC		High NFC		Low NFC		High NFC	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total time needed	155.2	33.4	124.3	28.7	136.2	33.9	129.5	34.4
Time before first move	21.6	2.1	16.0	2.1	14.3	2.2	14.5	2.1
Time between moves	5.3	1.7	4.3	1.0	4.2	1.4	3.7	1.1
Superfluous moves	2.9	2.8	2.1	2.3	4.1	2.1	4.4	3.9
Correction moves	1.1	0.3	1.0	0.3	1.8	0.4	1.6	0.3
Reconsidered moves	0.5	0.5	0.4	0.5	1.7	0.5	2.4	0.5

Total time: time needed to complete a task

There were no significant main effects of interaction style or cognitive style on the average total time for the tasks. However, we did find the tendency that low-NFC subjects tended to need more time, $F(1,39)=3.58$, $p=0.07$, ($M=146$, $SD=34$ vs. $M=127$, $SD=31$). There was no effect of cognitive style.

Time before first move: time between facing/studying the problem and placing the first speaker

There was a significant main effect of interface style on the time before the first move in each of the 5 tasks, $F(1,39)=4.34$, $p<0.05$. Internalization subjects took more time than externalization subjects, $M=18.9$, $SD=1.5$ vs. $M=14.4$, $SD=1.6$. There was no significant effect of cognitive style.

Time between moves: time between placing one speaker and starting to place the next

There was a main effect of interface style on the average time *between* moves, $F(1,39)=4.82$, $p<0.05$. Internalization subjects took more time between moves than externalization subjects, $M=4.8$, $SD=1.4$ vs. $M=3.9$, $SD=1.3$. There was no significant effect of cognitive style.

Superfluous moves: all unnecessary moves (attempted, actually done, reconsidered etc.)

There was a significant main effect of interface style on the amount of superfluous moves, $F(1,39)=4.17$, $p<0.05$. Internalization subjects made fewer superfluous moves than externalization subjects, $M= 2.46$, $SD=0.61$ vs. $M=4.27$, $SD=0.63$. For cognitive style, there was no significant effect.

Correction moves: all legal moves that were actually done, minus the ideal amount of moves

The effect of interface style on the number of correction moves was nearly significant, $F(1,39)=3.80$, $p=0.06$. Externalization subjects made more correction moves than internalization subjects, $M=1.70$, SD 0.25 vs. $M=1.1$, $SD=0.24$. There was no significant effect of cognitive style.

Reconsidered moves: moves that were started, but reconsidered and put back during dragging

The effect of interface style on the number of reconsidered moves was significant too, $F(1,39)=9.59$, $p<0.01$. Internalization subjects reconsidered their moves less often than externalization subjects, M=0.46, SD=0.36 vs. M=2.05, SD=0.37. There was no significant effect of cognitive style.

Strategy analysis

Subjects who were required to internalize showed a tendency to use the 'most constraints first' strategy more often than subjects in the externalization condition, but it was just a tendency ($F(1,39)=3.21$, $p=0.08$). Internalization subjects used that strategy 2.4 times (SD=1.76) out of 5 (tasks) whereas externalization used it 1.5 times out of 5 (SD=1.5). There were no effects of cognitive style.

Knowledge

The effect of interface style on answers to *declarative knowledge* questions, was practically significant at $F(1,38)=3.73$, $p=0.06$. Internalization subjects answered more of those questions correctly than externalization subjects (M=8.0, SD=0.2 vs. M=7.7, SD=0.7). The scores on *procedural knowledge* showed no differences for interface style. No effects of cognitive style were found.

Conclusion and Discussion

Our first hypothesis stating that internalization leads to more planning and better performance is supported. Internalization resulted in longer thinking times before starting to work on the problem and to more time between moves. It indicates that when information has to be internalized, more contemplation is provoked and users ponder longer before acting. With the move-based measures the issue was not so much "can they solve it?" but "how smart or economical do they solve it?". Internalization subjects solved the problems with fewer superfluous moves, thus with greater economy. These moves included self-correcting moves after being stuck, illegal moves and reconsidered moves (changing your mind *while* making the move). We infer that this stems from better planning, confirming O'Hara and Payne (1998) who found that a plan-based approach resulted in fewer moves than a display-based approach, and that "backtracking" (undo a move and return to the previous situation) occurs more during display-based behavior. Our results suggest that internalization provokes more "thinking before acting" than externalization. Regarding the strategy that subjects chose to use, a qualitative analysis of the results also indicated a more plan-based approach by internalization subjects. They filled the timetable by first scheduling speakers with the most constraints more often. This strategy suggests planning, because people think about whom they are going to schedule before starting with the task. It will be interesting to examine *strategy choice* more deeply in the future. Declarative knowledge was tested afterwards by giving subjects questions in which they had to judge situations where rules (sometimes) were violated. The effect of interface style on declarative knowledge was almost significant; internalization subjects gave more correct answers. Perhaps the fact that they planned more in the previous tasks caused a training effect that made them more accurate. The procedural knowledge questions focused on insight on solving the problem. Here, interface style had no influence, perhaps not surprising, since the problems were not so difficult and all subjects solved them eventually. This confirms earlier findings of Van Nimwegen et al. (2004, 2005): a positive effect of internalization on declarative knowledge, and not on procedural knowledge. The second hypothesis was rejected. Pre-existing attitudes towards problem solving along the dimensions of NFC had no effect on performance or knowledge. Only interface style predicted problem solving behavior.

To sum up conclusions, not at any measure, externalization resulted in better performance. Once more we found positive effects of *internalization* on problem-solving behavior: it led to more plan-based behavior, smarter solution paths and better declarative knowledge. Externalization led to a more display-based approach resulting in less economic solutions and shallower thinking. It is worthwhile to reflect on *what* was externalized and visualized. The interface showed legal actions, the outcome of the *application* of the rules, a common feature in a broad range of software applications. We showed that this had undesirable effects. One has to be careful with providing interface cues that give away too much and must design in such a manner that the way users think and act is optimally supported. Designers could consider making interactions "less assisted" to persuade users into specific behavior. This issue is beyond plain usability issues and focuses on more meta cognitive aspects of interface-induced behavior such as planfulness and user engagement. Also Guttormsen Schar, Schluep, Schierz and Krueger (2000) recognize the importance of other interface design standards than *only* those suggested by common usability guidelines. They stated that "*the user-interface can play a major role in the success of learning by supporting or inhibiting certain strategies*". They do not recommend less user-friendly interaction design, but propose to extend usability guidelines with extra cognitive factors, because usability (including user satisfaction) should not be optimized at the cost of learning performance. It is a challenge to understand how people react to interface information (based on cognitive findings). Our work contributes to building bridges between cognitive science, human computer interaction and educational practices and can be valuable in the development of applications in the realms of education, multimedia learning or game based learning. Tweaking a small part of the interface had impact on behavior, but externalization and internalization were not extremes on a continuum. It refers to the *amount* of externalization. In the future it will be interesting to *adaptively varying* the level of externalization, depending on performance (Brusilovsky, 2001).

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Acknowledgments

We thank Hermina Schijf (Utrecht University) for her involvement and assistance during this research project.