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GIVING THE LEARNERS CONTROL OF NAVIGATION: COGNITIVE GAINS AND LOSSES

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Abstract

E-learning often involves exploration of the information space that is somewhat similar to the exploration of space in the real world. Initial paths taken in any environment (be it a physical, virtual, or any other type) will not only guide the discoveries of what the environment contains, but also formulate the underlying organising principles. The suggested route in an art gallery frequently presents artworks that are either chronological or conceptually tied together. Deviating from this –and taking a route of our own, if at all possible– might be either confusing or insightful. The structure of the information, and the control that the learners have in exploring it, plays a major role in determining mental representations and learning. In the virtual world these possibilities and degrees of freedom in navigation are less constrained than in the physical world, and thus, can be colossal. The question that arises is what are the gains and losses of allowing the learners to control their explorations in an information space? To investigate this, we designed three e-learning environments that differed in their navigational possibilities and structure, but all contained the same eight topics to be learned. The topics in the first environment (*Linear*) were in a strict order and the layout did not allow any alternation from this defined sequence of page visits. With this Linear structure, the learners had very little control over their navigation as they could only continue to the next topic in this sequence or go back to the previous topic. The second environment (*Star*) partially restricted control by connecting the topics through a central index page. The third environment (*Interconnected*) gave full navigational control to the participants, as every topic was accessible from each of the other topics. Detailed navigational behaviour was recorded and learning efficiency was assessed. Participants answered questions immediately after the exposure of the hyperlinked pages and after a delay of two weeks in order to evaluate both short and long term learning outcomes. In this paper, we describe and interpret the results from the experiment with specific attention on how user control in e-learning can enhance efficiency in one case; while hinders it in others.

Keywords
E-learning, information foraging, spatial navigation, technology enhanced learning, user control, web design.

1. BACKGROUND

Information space in an e-learning environment encompasses a set of distributed pages across a hyperlinked website [2]. Following graph theory notations, an individual page is referred to as a node and a link between two nodes as an edge [11]. A single node, however, contains only a fraction of the overall information available within the environment and to acquire comprehensive knowledge the learner has to navigate through the nodes via the available edges. The act of visiting other nodes includes a navigational energy cost that is analogous to physical steps taken in the real world. The learner invests equal navigational energy for each node visited, however the amount of information acquired (cognitive gain) might not be the same at all nodes. Previously non-visited nodes, for example, are more likely to contain novel information that the learner could process. On the other hand, a better understanding of the material might require repeated visits to the same node, which could increase the navigational energy investment for the same cognitive benefit. When navigating through an information space the learner not only acquires content knowledge but also learns about the spatial layout of the learning environment. This approach of user navigation is based on the theory of information foraging [13]. The theory assumes that learners continuously re-evaluate their expected utilities by cost-benefit analyses. More recent explanations argue that most users, however, adopt only a limited number of strategies when navigating through an e-learning environment, even if their comprehension of the material is poor [10, 18]. Learning in a hyperlinked environment therefore could either enhance or hinder efficiency, depending on a variety of factors, including the cognitive mechanisms that are not yet fully understood.

Navigation in the informational space is similar to navigation in real space in a sense that it is spatially determined [3]. The routes in a hierarchically and semantically structured informational space are the node visit sequences. The users – at each node – have to allocate their cognitive and energy resources on (i) navigational tasks: planning and executing routes; (ii) informational tasks: learning about the content; and (iii) task management: coordinating informational and navigational task [7]. A classic real world example is the art museum problem (originally posed by [5]). This navigational problem relates to the information retrieval difficulties when visiting a huge art museum without detailed encoding of some of the specific art works or without conceptually focusing on a particular aspect (e.g., modernism) of the whole exhibition. In hypertext systems with high cognitive navigational costs, the demands might exceed the user's task management capacities, who could as a result become disoriented and ultimately get lost [5]. Consequently, the applied strategies of how people deal with the distributed information in a hypertext environment will adapt to the interaction between the informational and navigational demands [2, 6, 7, 13].

Some e-learning layouts are designed to determine the navigational behaviour by varying the amount of control the users can have. We define control in the context of this paper as the ability of the user to individually determine the order of appearance of the learning material [4, 16]. The effects of allowing control to the e-learners have been studied in relation to the level of expertise [12, 16], hypertext structures [9], learning performance [17] and other individual differences [15]. Although the findings from previous studies are not conclusive, in general, higher control tends to be perceived as an enhancing factor if the user is experienced in the applied information technology [16]. On the other hand, less experienced users could become overwhelmed by the high degrees of options that control provides them; hence their performance deteriorates. This negative effect is believed to originate in a memory encoding inhibition by overly complex informational demands [17]. However, previous literature on user control in e-learning environments lacks quantitative investigation into the interaction between the navigational and informational tasks.

The present experiment was designed with the view to amend the gap in the literature and investigated how the different levels of navigation control in e-learning environments affected actual navigation behaviour. As a novel aspect to previous research, both short and long term memory were assessed. Three e-learning environments were created with increasing level of control given to the participants. The environments differed from each other only in their edge structures (navigational demand), but not in their contents (informational demand). One of the three environments offered sequential routes (high energy demand and low cognitive demand), whereas the other two environments had highly or moderately complex route structures (low or moderate energy demand and high cognitive demands). Learning in the Linear environment with less control should result in higher navigation activity (i.e., more node visits) and consequently more vivid immediate memory of the content. However, the higher navigational energy demand is expected to result in less integrated knowledge of the relationships between the topics. In other words, short term advantage of higher exposure to the learning material is expected to attenuate with time. On the other hand, more navigationally complex environments should have less effective immediate learning outcomes, due to the increased informational demand. Nevertheless, complexity in the layout should enhance information retrieval and long term recall performance.

2. METHOD

2.1 Participants

One hundred and eight students from the University of Southampton volunteered to participate in the present study. Participants were recruited from an optional psychology course and they received course credits for their participation. The experiment complied with the requirements of the School of Psychology, University of Southampton's Ethics Board. All the participants gave informed consent and they were debriefed with the aims of this research after completion of the experiment.

2.2 Design and Materials

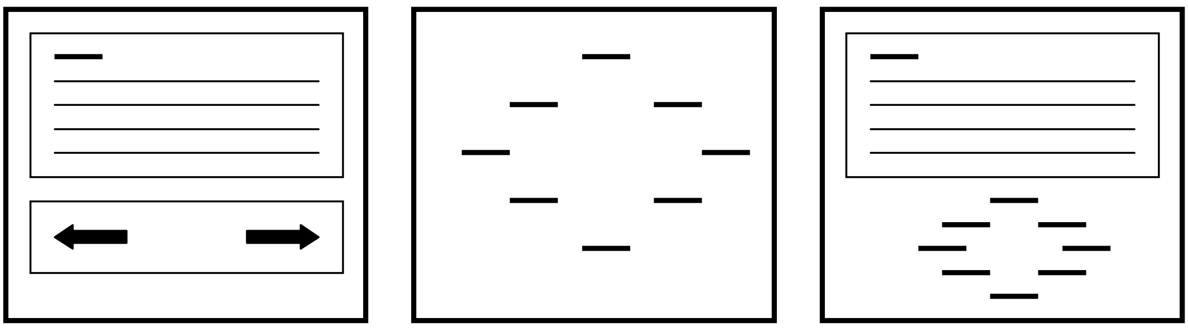
The study involved two tasks: computer-based learning material and a paper-based questionnaire. The computer-based task consisted of an e-learning session, which was purposely designed and programmed for the present study. The hyperlinked pages and the algorithms employed to record user behaviour were programmed using the HTML, PHP, AJAX and JavaScript programming languages and the MySQL relational database management system. The experiment took place in multiple consecutive group sessions in a lecture theatre with 60 standard PC computers. The material was presented on 15-inch monitors with standardized screen resolution. In this mode no scrolling was required to read the learning content. All computers were running Microsoft Internet Explorer 6.0 in full screen mode.

For the e-learning task, the material involved eight topics of human memory that were related to the cognitive mechanisms of learning and forgetting. Each topic was explained on a single node (page). All three e-learning environments presented the material in a framed box that occupied the top two third of the screen. The font sizes & styles, colours and frames remained constant throughout all conditions. A link to terminate the study at any time was accessible at the bottom of the screen.

Although the content of the learning material was the same for all participants, we designed three hypertext environments that differed in their hyperlink options (edge structure). The first environment (Linear) presented the nodes sequentially (see Fig. 1a). Control of navigation was limited to two arrows positioned at the left and right bottom of the screen. From each node, participants could only move to the subsequent node, or one back to the previous node. This arrangement did not allow alternation from a set order of navigation and there was no overview of how the nodes are linked to each other. The only indicator was the number of the current node out of the total number of nodes shown between the two arrows. In order to avoid order effects, the page sequences varied randomly across participants.

The second environment (Star) included and started with a central index page, where the names of all the eight nodes were listed along a circle (see Fig. 1b). The order of nodes presented on the index page was randomised across participants. Any nodes could only be chosen from the index page. Once a particular node was visited, the participants always had to navigate back to the index page in order to choose the next node. Therefore, this environment partially restricted control by enabling free navigation but only from an index page.

In the third environment (Interconnected), all nodes were accessible at all times during learning without a central page or other browsing limitations (see Fig. 1c). The eight nodes were listed along a circle at the bottom of the screen, while the currently selected content was shown above. This setting granted total control to the participants as they could freely and directly navigate and visit any page from any page.



(a) Linear layout (b) Index page in Star layout (c) Interconnected layout

Fig.1. Schematic diagram of the three (Linear, Star, Interconnected) e-learning environments

Once participants finished the computer-based task, they were immediately administered with a paper-based questionnaire that assessed their learning. This involved questions about the learnt material and the overall impressions of their specific e-learning condition. Questions were aiming to assess the level of the acquired knowledge and particularly to see what was the efficiency of learning within each group. In addition, participants were asked to sketch a graphical representation of how they imagined the links between the learnt topics. The number of nodes and connections between them (edges) on these hand drawn graphs were recorded.

2.3 Procedure

The experiment was started with an electronic consent form shown to the participant. They were asked to read it carefully and with their agreement they continue to the instructions page. After entering basic demographic information (e.g., age and gender), participants began the actual experiment and were directed to the first page of one of the three e-learning environments (Linear, Star or Interconnected). Participants were automatically assigned to one of the conditions by the server in order to keep the groups equal in their size. The computer recorded detailed navigational behaviour for each participant. This included total number of nodes visited, average and median node viewing times and page viewing sequences for each participant and for each node separately. After completion of the computer-based task, participants were provided with the paper questionnaire. There was no time limit for the participants to finish the tasks, however, the whole experiment did not take longer than 60 minutes.

2.4 Results

Navigation behaviour and learning performance differences between the three e-learning environments were analysed with one-way ANOVAs or – where parametric assumptions are not met– their non-parametric equivalent. All navigation activity was included in the analysis, even when participants were rapidly flipping through some of the nodes.

Navigation Behaviour and Complexity

Participants spent equal amount of time viewing the topic pages, $F(2, 106) = 2.51$, n.s. (median time per node = 60.65 seconds). However, the number of nodes visited was significantly different, $F(2, 106) = 12.42$, $p<.001$. Post-hoc t-tests with Bonferroni corrections ($p = .05/3 = .017$) revealed that the Linear group (M = 16.58, SE = 1.35) visited significantly more nodes than the Star (M = 10.40, SE = .62) or the Interconnected (M = 10.88, SE = .76).

In addition, navigation complexity measures including the number of links followed per node (fan degree; [14]) and regular returns to previously visited nodes (path density; [14]) were equally high for the Linear (M = 2.07, SE = .17 and M = .29, SE = .02, respectively) and for the Star (M = 2.39, SE = .13 and M = .30, SE = .02, respectively) conditions. These two measures of navigation complexity were significantly lower in the Interconnected group, (M = 1.40, SE = .09 and M = .20, SE = .01, respectively).

Learning Performance

There was a significant group difference between the scores on short essays immediately after the e-learning session, Kruskal-Wallis $H(2) = 6.75$, $p<.05$. Non-parametric Mann-Whitney post-hoc tests showed that Linear group differed significantly from the Interconnected group, W = 884.50, $p<.01$. Linear group (M = 16.91, SE = .78) remembered the most topics correctly, while the Interconnected group performed the worst (M = 13.88, SE = .90). The Star group performed moderately (M = 14.80, SE = .93) and did not differ significantly from the two other groups.

The difference between the three groups disappeared when the participants were re-assessed two weeks later with the same short essay, $H(2) = 3.53$, n.s. The grand mean score of the groups on the second assessment was 8.05 topics (SE = .41) compared to 15.24 topics (SE = .51) immediately after learning. Nevertheless, the difference in scores for the first and second test was less for participants in the Interconnected group than in the Linear group (W = 462.00, $p<.05$, Interconnected M = 5.83 topics forgotten, SE = .79; Linear M = 8.5 topics forgotten, SE = .89). The decay rate in the Star group (M = 7.32, SE = .82) did not differ significantly from either of the other two groups (W = 729.00 and W = 522.00, both n.s., in comparison with the Linear and the Interconnected groups respectively).

Mental Maps

As part of their assessment, participants were asked to sketch a map of how they imagined the topics were related to each other. Out of the 108 participants, only 61 (56%) responded to this question immediately after learning and only 35 (32%) after the two-week delay. The number of participants, who managed to draw a map, was equally distributed amongst the three groups (28 Linear, 22 Star and 22 Interconnected). When analysing these maps, all recognisable drawn nodes was counted, which were named after one of the original topics. Edges (links between nodes) were also recorded, when any two drawn nodes were connected with a line.

The mean number of drawn nodes immediately after learning was 8.70 (SE = .65) for the Linear, 4.62 (SE = .90) for the Star and 6.08 (SE = .76) for the Interconnected group. This was a significant overall difference $H(2) = 12.45$, $p<.01$, yet the Linear and Interconnected groups did not differ from each other (W = 332.00, n.s.). Similarly, the number of edges were significantly different between the three groups (Linear M = 6.20, SE = .85; Star M = 3.54, SE = .99; Interconnected M = 4.50, SE = 1.21), $H(2) = 7.08$, $p<.05$. However, in this case the Star and the Interconnected groups did not differ (W = 405.00, n.s.), whereas the other two comparisons were significant (W = 315.00, $p<.05$ and W = 356.00, $p<.05$, for the Linear-Interconnected and Linear-Star respectively).

Two weeks later, when the participants redrew their graphs the same pattern of group difference was observed for the number of nodes, $H(2) = 6.89$, $p<.05$; Linear M = 4.80, SE = .98; Star M = 2.15, SE = .63; Interconnected M = 5.17, SE = .96. On the other hand, this time the number of drawn edges (grand M = 2.83, SE = .55) was equal in all three conditions, $H(2) = 3.32$, n.s.

3. GENERAL DISCUSSION

This study investigated how different designs in e-learning environments affected navigation and learning with a specific focus on navigation control. The three environments used provided either low, moderate or high degrees of freedom in terms of navigational control given to the participants. We found that while the participants spent equal amount of time learning the material in all the three structures, the Linear group visited more nodes during this time than the Star and the Interconnected groups. This suggests that linearly structured e-learning settings force the learners to intensify their navigation activity when exploring a novel environment and reduce the time invested into any individual node.

There can be several reasons for this increased navigational investment in the Linear condition. The lack of an overview in the linear structure, for instance, could hinder planning of the learning routes and, thus, increase returns to previously visited nodes. On the other hand, in those environments where all nodes were more readily accessible from the first encounter a simple, effortless and better-planned navigation strategy should be sufficient to visit all the pages. Although the Interconnected group seemed to apply such simple navigation strategy, the Star group – with site overview on the index page – was more similar to the Linear group with a rather complex navigation behaviour as shown by the graph theory measures (fan degree & path density). Consequently, the lack of overview is unlikely to be the primary cause for the increased navigation activity.

Alternatively, we need to consider further informational foraging strategies that exist in e-learning environments. Participants in linear hyperlink structures cannot get an instant understanding of how the nodes are related to each other. To compensate for this informational deficit, they should increase their navigational energy expenses; hence, they visit more nodes. E-learning structures with limited user control (e.g., Linear & Star) force the participants to use shorter planned navigation sequences and more frequent returns to previously visited pages. In environments with more user control (e.g., Interconnected), participants are not necessitated to revisit nodes more than once, as they can remember and monitor their planned routes throughout the whole session. In fact, this is exactly what was found in the present experiment. This finding supports the claim that hyperlink structure influences navigation behaviour via the amount of control given to the participants.

Navigational behaviour in itself is not very informative and has to be accompanied with learning performance measures in order to evaluate their effectiveness. Our results showed that the increased navigational activity in the Linear group was associated with the best short term learning performance, whereas the Interconnected group performed the worst and the Star in between. This finding reinforces previous findings that linear structures are more efficient than hierarchical or non-linear ones (e.g., [9, 17]). Nevertheless, in all these studies performance has only been measured immediately after learning, but not weeks following the e-learning session.

In the present study, we assessed long term learning effectiveness and found that the advantage of the Linear group disappeared when participants were re-examined two weeks after their e-learning session. In effect, there was a significantly greater drop in learning performance levels in the Linear group, whereas the Interconnected and Star groups performed steadily over time. This suggests that although e-learning environments providing high navigational freedom have smaller immediate learning effectiveness, the learnt information more effectively than structures with restricted control.

Long term memory processing is both semantic and relational – in other words, providing learning material in a coherent structure can be used as a tool for memory [1]. Participants in the Interconnected group were not only spending their cognitive resources on serially accessing, learning and remembering the e-content but they were also planning, executing and monitoring the sequence of their own exploration. This extra navigational strategy component could have led to a decreased immediate performance, but also to a lower rate of memory decay. On the other hand, the Linear group could focus all their cognitive capacity in memorizing the nodes right after learning without the need to plan further steps. Although this might increase subsequent efficiency, but without a deeper cognitive processing into a relational memory structure, the topics could more easily be forgotten. This interpretation was further tested with analysing the drawings of the participants, whereby they graphically represented the relations between the newly learnt topics.

Without an attempt to abundantly analyse the mental maps of the participants, we recorded only the number of drawn nodes and their connecting edges on these sketch maps. These measures could provide an estimate of how the participants mentally represented the newly learnt topics and their relations to each other (for an overview of mental imagery see [8]). The task was found to be either relatively difficult or unclear as only 61% and 32% of the participants could draw such a map at all (immediately after learning and two weeks after, respectively). However, there were an equal number of drawings from participants initially assigned to the three environments, which means that the completion of the task did not depend on the learning structures.

The mental map drawing task confirmed the previous finding that the conceptual links between the nodes faded more easily with time in the Linear condition than in the more complex Star or Interconnected ones. It also showed that forgetting targeted the remembered edges, but not the number of independent nodes. More freedom in navigational control (i.e., Interconnected structure) given to the participants ensured that the learnt information was remembered better by integrating into a relational memory system.

In summary, this study investigated navigation behaviour, user control and memory performance in three different e-learning environments. The experiment provided good evidence on a dissociation between two types of information foraging demands: an informational demand (how much content will be remembered) and a navigational demand (what route will be taken). Our data confirmed that as hyperlink complexity and, thus, navigational control became more cognitively demanding, short term learning performances decreased. It was harder to remember all the topics correctly immediately after learning if more than one route was available to navigate through the material. Cognitive resources were divided in these cases between the navigational task and the informational task. The benefit of higher degrees of freedom in user control was the more integrated knowledge representation and consequently less forgetting in the long term. Limited user control, on the other hand, resulted in greater navigation activity and better performance in the subsequent memory task. This advantage disappeared, however, two weeks after the e-learning session, suggesting that freedom to navigate within the material in hyperlinked environments is required for long term, relational learning.

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