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Kochiu Wu Hung-Chun Chen

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Children use second-and third-dimensional digital library interfaces

Kochiu Wu and Hung-Chun Chen
National Taipei University of Technology, Taipei City, Taiwan

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Abstract

Purpose – The purpose of this paper is to explore children's spatial cognitive abilities as they engaged in information-seeking behaviors on two-dimensional (2D) and three-dimensional (3D) digital interfaces.

Design/methodology/approach – Children between the ages of seven and 11 were observed as they browsed either a 2D or 3D navigation interface for a children's digital library. Data regarding their use of the overview function and depth cues were analyzed to reveal the relationships between search performance efficiency, precision, and effectiveness and the associative memory, visualization memory, and spatial visualization abilities of the user.

Findings – Children spent less time using the 2D interface when compared to time spent using the 3D interface. Children exhibited better performance precision when using the 3D interface. Children applied exhaustive strategies and more varied cognitive skills across different tasks when using the 2D interface, and applied a more focussed approach when using the 3D interface.

Originality/value – The cognitive abilities of children are not yet fully developed, so they require a unique user interface when browsing digital libraries. This study served the practical purpose of developing a game-like user interface for ease of use. Providing an effective overview function allows young users with less developed cognitive abilities to navigate informational cues. They can then build an effective mind map and implement efficient way-finding strategies.

Keywords Design, Information visualization, Virtual worlds, Information space, Search user interfaces, Way-finding

Paper type Research paper

Introduction

Children tend to like graphic interface designs (Bilal, 2005) and many such interfaces have been developed to satisfy their information-seeking needs (Hutchinson *et al.*, 2007; Gossen and Nürnberger, 2013). Search interfaces are generally divided into "query interfaces" and "navigation interfaces." Though it may seem convenient enough for a young child to type the appropriate keywords on a query interface, a child usually lacks the basic framework of knowledge and literacy that adults have. They are therefore inclined to have a skill breakdown due to insufficiency of knowledge. Navigation interfaces, meanwhile, help children to obtain information through browsing; children are better able to comprehend the structure of the interface via information visualization so they can then acquire what they are seeking.

Adult readers generally know how to use advanced functions such as keyword queries or hyperlinks in a digital library, so they are able to find the data or the publication they seek. They are also capable of utilizing abstract visual tools to guide them in navigation. Children, however, can only consult their limited life experiences as they are still at the concrete operational stage of cognitive development. Past research results have shown that children are very different from their adult counterparts when seeking information

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on websites. To be more specific, their operational behavior, cognitive construction, and their methods of integrating knowledge are different from adults (Bilal and Kirby, 2002; Shenton and Dixon, 2004). Since people live in a three-dimensional (3D) environment and are well-versed in the navigation of such a space, it makes sense for the computer-based virtual world to look similar to the real world. A virtual library displays its collection of books and publications using themes and classification numbers. Readers can depend on their existing space experience and adopt a goal-oriented approach, i.e. way-finding in the real environment, when searching for their targets (Beheshti, 2012). In this study, we employed computer technology to create a virtual environment in which children can freely explore the virtual space through choosing concrete image icons and databases arranged in themes. This interface was constructed in accordance with children's cognitive abilities and browsing skills, with the aim of enhancing their digital library experience.

We used the digital library interface as a model to examine the information-seeking performance of children. Through this investigation we were able to examine the relationship between children's spatial cognitive abilities (spatial visualization, visualization memory, and associative memory) and their searching behaviors. We then explain the disparate methods employed by children in a two-dimensional (2D) vs a 3D environment. Children were able to use an overview to develop an understanding of the theme in each distinct information space while also displaying other responsive skills. The results of this research contribute to our understanding of how children are able to incorporate way-finding behavior with relevant strategies gained from their real-world experiences while searching electronic books from a digital library in a web-based virtual world.

Literature

Navigation design and depth cues

Virtual worlds (VW) are 3D spaces that allow users to maneuver their avatars in an interactive environment. Previously, this was mostly seen in video games, although Messinger *et al.* (2009) explain that now the virtual world has gradually shifted from gaming to functional online services. When a virtual information space provides more search options on one layer through the addition of stories, treasure hunting, visualization, and virtual backgrounds, the navigation interface has better usability and meets standards for children's educational and developmental psychology in terms of conceptualization, plots and premises, and correlated life experiences (Wu *et al.*, 2014). This can significantly improve the interface design of a children's digital library.

When a child uses a Boolean query in a category browser with different hierarchical branches, the child has to focus on a specific topic and navigate top-level categories sequentially; this process is perhaps too abstract for a child to operate (Hutchinson *et al.*, 2007). Koshman (2006) analyzes the placement of the icons that are associated with document representation in a visualized information system through the lens of the Gestalt theoretical constructs of pattern perception, which are involved in interpreting a graphical display. A good information interface structure gives users a clear understanding of what they perceive, although there is no perfect structure for all users. As the structures of virtual environments have become increasingly complex, there has been considerable interest in the question of "depth cues" and whether a 3D visualization will reveal more useful information to the searcher than a 2D visualization (Westerman and Cribbin, 2000). While interface metaphors that are cognitive models for interaction profoundly influence the design of interfaces for data spaces, designers have to consider the metaphors for VW interfaces, either from a turntable (2D or egocentric) approach, or from a flying helicopter (3D or exocentric) approach (Ware, 2013, p. 355).

The type of task also affects people's perception of depth cues when searching a virtual environment. Risden *et al.* (2000) compared the behavior of engineers when browsing a huge amount of internet information on conventional 2D browsers or on a 3D hyperbolic graphic interface and discovered that even if most engineers consider the 3D interface to be better when searching within existing categories, they preferred the 2D interface during search tasks for new categories. Perception and action are intertwined, and to understand space perception (for visualized interface designs), designers need to understand the purpose behind the information-seeking behavior. Risden *et al.* suggest that the two interfaces should be combined to make an optimum visual presentation of the large amount of information found on the internet.

Way-finding strategy and mind maps

Sitemaps are a visualized representation of an information system. They reveal the structure and hierarchy of a website, and are widely used in information structuring. The sitemap collects information from the main page, categorizes it, and provides users with corresponding links to all of the information so that information can be acquired quickly. Sitemaps are supposed to utilize the fewest words and the simplest language to describe complex ideas to the user. With a sitemap, a user should be able to answer the following questions: where am I now? How do I get to where I want to go? Where do I want to go? Where will this icon take me? (Danielson, 2002). Lynch and Horton (2009) see web navigation as a kind of spatial way-finding behavior. Analysis of users' website navigation can provide developers with solutions for improving the information structure and design of the website. However, website structure does not render real spatiality and cannot provide tangible navigation, yet similarities exist in website navigation and the real environment. In website navigation, users click the button that leads to the next page, and the webpage changes directly from page to page without leaving a record of user's experience. Hyperlinks cut off the continuity of navigation memory and thus affect way-finding behavior. In conclusion, the differences between web navigation and navigation in the real environment are: first, there's no sense of movement when browsing the internet. Second, there is no compass or direction on the internet. Third, there is no referential point on the internet. Downs and Stea (1973) submit that when users navigate, they are not simply carrying out a single task or even just trying to determine the relative locations of themselves, the space, and the target. Rather, they learn, through continual exploration, whether it is appropriate to try a new route or adopt new strategies. They also discover how the outside environment differs from the inner operations of their minds. Cognitive way-finding processes are closely related to spatial knowledge. Kosslyn (1987) suggests two kinds of knowledge representations: categorical information (or route spatial knowledge) and coordinate representation (or survey spatial knowledge). In a virtual space interface, route knowledge is incorporated with the characteristics of the information structure, and the movements among information nodes are linear. Route knowledge is better employed when there is simple page representation and fewer functions, with only a small amount of information shown at one time. This decreases information overload. However, a less complete information structure can be a disadvantage. When a user tries to perform cross-functional or cross-page operations, the incomplete information structure might require an overwhelming amount of information processing and/or memory. Survey knowledge refers to an individual's understanding of the sequence of events or the overall structure of a task, and an individual using survey knowledge adopts absolute coordinates (exocentric) as a way-finding strategy. In a virtual space interface, an effective survey knowledge feature can give an individual a full picture of all the functions of an interface and where they are placed within the interface. The advantage of having survey knowledge lies in that it helps the user easily operate among various functions and information routes without being limited to linear requirements. Yet when too much information is shown at the one time, users may experience information processing overload (Kitchin, 1997). Munzer *et al.* (2006) suggest that users incidentally learn only the information which is encoded, transformed, and memorized during the primary way-finding activity. Zhang (2008) demonstrates that users could improve their navigation performances for tasks at different scale levels if they could couple spatial knowledge and movement and move them easily across the scale. Henry and Polys (2012) show that immersion and navigation techniques can affect a user's acquisition of spatial knowledge regarding abstract networks in an immersive virtual environment.

Therefore way-finding strategies are referred to as evaluation strategies that form in accordance with users' cognition before starting off on way-finding. With the focus on both survey and route strategy, it is worth further research about how children seek information using different spatial abilities along with the two strategies in a metaphoric, scale-adjustable, virtual information space.

Research questions

Westerman and Cribbin (2000) designed a virtual information space that could be searched using either a 2D or 3D format. In this virtual interface, the spatial location of the informational nodes (documents) is determined by the semantic content. Westerman and Cribbin (2000) found that when they used the Paper Folding Test (VZ2) and Object-Number Test (MA2) to measure the cognitive abilities of users, the benefits of the additional information conveyed by a 3D environment did not outweigh the associated additional cognitive demands. Westerman *et al.* (2005) found that participants adopted distinct strategies when they tried to identify documents relevant to a specified topic while operating in a virtual information space; the strategy applied in a 2D environment is comprised of an "exhaustive" approach, while the 3D environment inspires a more "focused" approach.

People perceive the world by first gathering information from multiple channels and then making analyses according to that information. When browsing through a digital library, the first task of the user is to understand the thematic structure behind the search interface, and then find the information that is needed through functions provided by the interface. When compared with the information space model that was developed by Westerman and Cribbin (2000), the information space model for children (C-ISM) used in this study differed in that it did not use an abstract white sphere, but instead used icons indicating information nodes; the icons were more effective at conveying semantic information to children. Mapping information is presented in a structure similar to that used by elementary school curriculum. This replaced the abstract document similarity matrix that makes use of angles and distance. To employ a third spatial dimension, the visual 3D sitemap was replaced with the ability to let users choose, browse, and rotate the virtual world. Through these changes, the C-ISM allowed the children to use more natural information searching behaviors and spatial cognitive abilities that are more appropriate to the concrete operational stage.

By changing the interface from 2D to 3D, we were able to gather more data about children's information-seeking behaviors, which leads to a deeper understanding of information performance as it is performed in different dimensions, and how children understand this information.

Greene *et al.* (2000, p. 381) argue that a good overview "provides users with an immediate appreciation for the size and extent of the collection of objects the overview represents." Thus the way that people perform an overview of an information space may be influenced by the different types of tasks they wish to accomplish there, for example monitoring, navigating, and planning. Hornbæk and Hertzum (2011, p. 520) explain that "understanding and supporting the active creation and continuous recreation of awareness appear to be major challenges for future research in information visualization." They then suggest three areas to focus on in research related to acquiring an overview; first, the role of details in obtaining an overview; whether an overview develops from a primary perception of global or local features; second, how the gaining of awareness in an information space allocates for user dealing with the visuals in order to survey the information space; and third, the user's process of integration; the integration involved in upholding a consistent mental picture of an changing situation proposes that overviews might not only disseminate information but also seek to incorporate with multiple pieces of information.

Information visualization is an important component of visual analysis, and an effective overview is one of the more important functions in information visualization as it involves a user's spatial visualization and spatial memory skills. As information searching is a task-oriented job, it requires that the users have associative memory that matches the memory of the task at hand. The role played by each of the three cognitive abilities-associative memory, visual memory, visualization ability, when children are seeking information in a virtual information space has yet to be explained.

Research method

Participants

According to Piaget, children in concrete operational stage (aged 7-11) are developing their ability to reason with logic, categorize items, and compare the relationships between things. Children at this age are experiencing fast visual development, which plays an important role in interface design (Hourcade, 2007). As a result, this experiment analyzed the performance of a group of children aged 7-11 as they used the interface in an effort to better understand how children with disparate cognitive and visual abilities perform when using virtual navigation interface.

A total of 281 students from second to fifth grade classes in Taipei participated in this study. Consent for the children to participate in the study was obtained before the research began. In total, 26 samples were incomplete, leaving a total of 255 valid samples, which represents a 91 percent response rate. The research randomly divided all students into three groups and asked them to use one of three different search interfaces: 128 participants used the 2D-extended interface (64 males and 64 females), 64 participants used the 3D-survey interface (35 males (54.7 percent), 29 females (45.3 percent)), and 63 participants used the 3D-route interface (30 males (47.6 percent), 33 females (52.4 percent)). The participants then took the Factor-Referenced Cognitive Test kit (FRCT) to determine their scores in three categories: Visualization, visual memory and associative memory. Visualization-VZ1 (Form Board Test, $M = 50.15$, $SD = 28.69$), VZ2 (Paper Folding Test, $M = 49.90$, $SD = 28.83$), and VZ3 (Surface Development Test, $M = 50.39$, $SD = 28.89$); Associative Memory-MA1 (Picture-Number Test, $M = 50.23$, SD = 28.84), MA2 (Object-Number Test, $M = 50.27$, SD = 28.72), and MA3 (First and Last Name Test, $M = 49.93$, SD = 28.85); and Visual Memory-MV1 (Shape Memory Test, $M = 50.06$, SD = 28.64), MV2 (Building Memory Test, $M = 50.06$, SD = 28.86), and MV3 (Map Memory Test, $M = 50.19$, SD = 28.62). Pearson Correlation analysis was then used to compare the correlation between the children's FRCT scores and their performance when it came to interface navigation efficiency, precision, and effectiveness.

Experimental design

We designed 2D-extended, 3D-survey, and 3D-route interfaces and set up three tasks to test the operational performance of the children. We utilized the usability test for human computer interfaces developed by Nielsen (2000), and then combined that score with the space navigation and relative way-finding parameters used by Westerman *et al.* (2005) and Lynch and Horton (2009). Efficiency was measured by examining the duration of time spent on a task. Precision was measured by counting the number of times the button (Found), category buttons and page buttons were clicked for comparison between tasks and databases in the process of information retrieval. Effectiveness was measured as follows:

$$F = \frac{2}{\frac{1}{r}+\frac{1}{p}}$$

F is the effectiveness; r the found, the number of times the button (Found) pushed; p the processing times (which was measured by counting the number of times each functional button was chosen in the process of a single searching task. For the 2D-extended interface, the buttons consist of left and right buttons, category buttons at the bottom of the page and over the screen, as well as previous page, next page, and leave the page buttons. For the 3D-survey and 3D-route interface, the buttons consisted of click-to-rotate, click-to-zoom, click-to-forward or backward, a category button for layer 1, and a category button for layer 2.

Design of experimental task

The experiment relied on the system to automatically convey the mission, collect the data, check if the participants had completed the task, and record the operational performance of users. After they were separated into groups, each participant received three tasks, and subsequent tasks only appeared when the previous one had been completed. Borlund and Dreier (2014) mentioned Ingwersen's definition of three information needs – verificative information need, (VIN, well-defined and stable), conscious topical information need (CIN, well-defined and more variable in nature), and muddled topical information need (MIN, poorly defined and presenting high cognitive uncertainty). The differences between the three needs lie in whether the information seeker has a thorough understanding of the search topic, the searching situation, and the structural stability of the search question. As a result, the VIN task in this experiment was to ask participants to look for daily assignments, then the CIN task was to look for comic books that were non-curriculum but widely loved by children, and the MIN task was to look for professional sports knowledge that might be unfamiliar. The tasks were designed to prove that interface spatiality is helpful for seeking information; therefore, the users were only told to find the database itself, instead of actually searching in the database:

- Task 1: you come across a problem when you are doing your biology assignment, and your teacher tells you that the "Taiwan Ecological Notes Database" might contain useful information. Now, try to find "Taiwan Ecological Notes Database."

- Task 2: when you want to take a look at some graphics, your teacher tells you that "Chijon Tsai's Comic Animation Database" might have some good references for you. Now, try to find "Chijon Tsai's Comic Animation Database."
- Task 3: you encounter problems when you are doing a physical assignment, and your teacher tells you that "Sports Animation" might have some useful information. Now, try to find "Sports Animation."

Developing virtual graphics for a children's digital library search interface

The 2D-extended interface (Figure 1) is a 2D space with all the nodes scattered on a single layer along the screen's horizontal line. Children use the mouse to move left and right and enter the database through a hyperlink after they click a node. The 3D-survey interface (Figure 2) has all the nodes gathered into five groups in the shape of cherry blossom, which offers a clear center and polar coordinates on a flat surface. An overview function allows the children to experience two visual hierarchies, either from above or from a flat angle. Children can use the overview function to get familiar with the entire structure of the database, then they can use the mouse scroll wheel to zoom in and out. They are able to use the mouse to go in every direction and click on specific nodes; however, processing and memorizing the theme map might increase the user's cognitive burden. Although the 3D-route interface (Figure 3) is a 3D, cherry blossom-shaped virtual space, users can only zoom and move around nodes using the mouse scroll wheel and the keyboard in a 2D interface. Yet because only a small amount of information is shown at one time, it is relatively easy for the children to process information.

Results and discussion

Comparison of children performances in 2D and 3D

According to Piaget's theory, children aged two-six are only capable of focussing on a single object whereas their 7-11-year-old counterparts are able to focus on multiple

Figure 1.
Two-dimensional, graphic hyperlinked search interface (2D-extended)

Figure 2.
Three-dimensional overlook, graphic search interface (3D-survey)

objects. It follows that they would be able to maneuver the 2D-extended and 3D (survey +route) interfaces in which multiple objects exist on different layers and form a knowledge map. The 2D interface is restricted through the screen display, so only some of the icons can be presented. Participants have to move horizontally from one corner of the interface to another in order to become familiar with the knowledge structure. The 3D interface comprises one more dimension than the 2D interface, and provides more spatial information (depth) that users might consider when comparing information spaces. Tory *et al.* (2007) revealed that in terms of information processing, users normally perform worse on 3D landscapes than they do on 2D. In Table I, a comparison of performances on 2D and 3D interfaces reveals the following: efficiency Task 1 $p = 0.004$, Task 2 $p = 0.000$, and Task 3 $p = 0.000$; precision Task 1 $p = 0.004$, Task 2 $p = 0.030$, and Task 3 $p = 0.450$; effectiveness Task 1 $p = 0.432$, Task 2 $p = 0.162$, and Task 3 $p = 0.004$. The results indicate that users spent less time when using the 2D interface. When it comes to choosing the correct icon, users performed better when using the 3D interface. Subsequently, we can be certain that users adopted a faster trial and error method on the 2D interface and a slower evaluate-before-choosing method on the 3D interface.

Knowledge structure and cognitive overload

The human perceptual system is highly attuned to images. In a sense, information visualization transforms abstract information into ideas that are comprehensible to humans, enabling users to acquire new insights into the previous information.

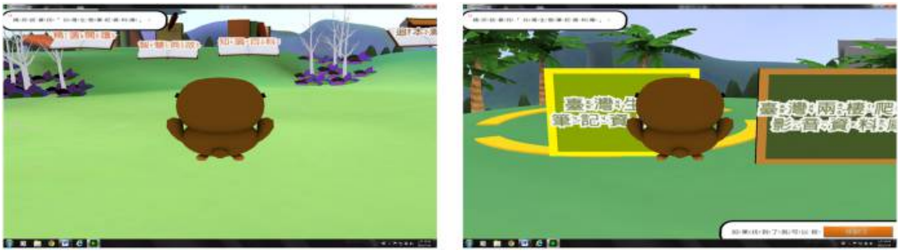

Figure 3.
Three-dimensional route, graphic search interface (3D-route)

Table I.
Independent samples *t*-test of searching performances in 2D and 3D, 3D-survey and 3D-route interfaces

	2D ($n = 128$)		3D ($n = 127$)			3D-survey ($n = 64$)		3D-route ($n = 63$)		
	M	SD	*M*	SD	*p*	*M*	SD	*M*	SD	*p*
Task 1										
Efficiency	80.16	115.54	122.04	112.44	0.004	94.88	89.42	149.63	126.61	0.006
Precision	28.51	41.08	16.72	19.29	0.004	10.88	10.01	22.65	24.15	0.001
Effectiveness	6.63	12.09	5.56	9.56	0.432	3.14	2.79	8.02	12.86	0.004
Task 2										
Efficiency	44.05	40.37	94.65	94.42	0.000	66.06	64.78	123.70	110.25	0.001
Precision	18.54	20.78	13.61	14.77	0.030	10.80	10.84	16.48	17.54	0.031
Effectiveness	2.77	3.85	3.80	7.35	0.162	2.47	2.71	5.14	9.94	0.043
Task 3										
Efficiency	14.64	21.93	29.23	26.29	0.000	18.44	19.36	40.19	27.94	0.000
Precision	3.93	9.10	4.57	2.67	0.450	4.08	2.69	5.06	2.58	0.037
Effectiveness	1.41	0.86	1.76	1.03	0.004	1.39	0.60	2.14	1.23	0.000

Task-relevant object information was stored using a verbal-propositional coding, and place information was stored in visual working memory. The 2D and 3D interfaces in this research allowed users to familiarize themselves with the location of the databases first, and then they were able to understand the thematic relationships between databases, and finally the users could build mind maps for future research. The act of searching is a means to some other end, rather than a goal in itself. When searching, one is focussed on the task. Competition among different cognitive tasks such as the perception of informational cues, memorization tasks, category comparison, search decisions, and perceptions regarding the fitness of the mind map – all of these tasks might accumulate, leading the searcher to experience cognitive overload, or a ceiling effect. Searching, as a cognitive task, requires so many different cognitive abilities, it is important to know how humans apply their abilities, particularly through the lens of their cognitive limitations.

In Figure 4, the initial FRCT performances showed the participants' skill level in the abilities that they would need when information seeking on the C-ISM. For Task 1, measures of abilities related to efficiency that showed significant correlation with performance on the 2D-extended interface are as follows: MA1($r = -0.235$, $p = 0.008$), MA2($r = -0.182$, $p = 0.040$), MA3($r = -0.329$, $p = 0.000$), and MV2($r = -0.260$, $p = 0.003$). Measures of abilities related to precision that showed significant correlation with performance on the 2D-extended interface are as follows: MA1 ($r = -0.260$, $p = 0.003$), MA3($r = -0.289$, $p = 0.001$), and MV2($r = -0.224$, $p = 0.011$). Measures of abilities related to effectiveness that showed significant correlation with performance on the 2D-extended interface are as follows: MA1($r = -0.243$, $p = 0.006$), MA2($r = -0.226$, $p = 0.010$), and MA3($r = -0.246$, $p = 0.005$). This explains that users rely on the awareness of the location of icons (MV2, Building Memory Test) to facilitate information seeking. With a solid command of the three memory abilities, users were able to conduct thematic comparisons and memorize the locations of icons. As the users concentrated on building their mind maps, part of the background information of the interface was not revealed. The resulting incompleteness of the mind map required the users to further explore the information space. The fact that users tried more operational functions on the 2D interface than they did on the 3D might indicate that when users were using the 2D interface, they were experiencing less cognitive overload. They were therefore less afraid of getting lost and more willing to try search strategies, visiting more information nodes in the process. It is worth noting that when the participants conducted the second task on the 2D interface, they performed differently owing to their different visual abilities. The abilities in question are VZ1($r = -0.312$, $p = 0.000$), VZ2($r = -0.199$, $p = 0.024$), VZ3($r = -0.225$, $p = 0.011$), and MV3($r = -0.190$, $p = 0.032$), which are related to efficiency; VZ1($r = -0.286$, $p = 0.001$), VZ3($r = -0.202$, $p = 0.022$) and MV3($r = -0.215$, $p = 0.015$), which are related to precision; and VZ2 ($r = -0.174$, $p = 0.050$), which is related to effectiveness. This shows that participants employed a visual assisted strategy when seeking information, perhaps trying to enhance the connection between the mind map and the information space. For the third task on the 2D interface, measures MA3 ($r = -0.279$, $p = 0.001$) and VZ3 ($r = -0.232$, $p = 0.008$), related to efficiency, MA3 ($r = -0.258$, $p = 0.003$) and VZ3 ($r = -0.194$, $p = 0.028$), related to precision, and MA3($r = -0.234$, $p = 0.008$) related to effectiveness. The results show that as the mind map became clearer with continued use of the interface, users adopted safer and more efficient approaches, combining users' operational features with their task memory –MA3 (First and Last Name Test) in order to take advantage of map expansion ability (VZ3, Surface Development Test).

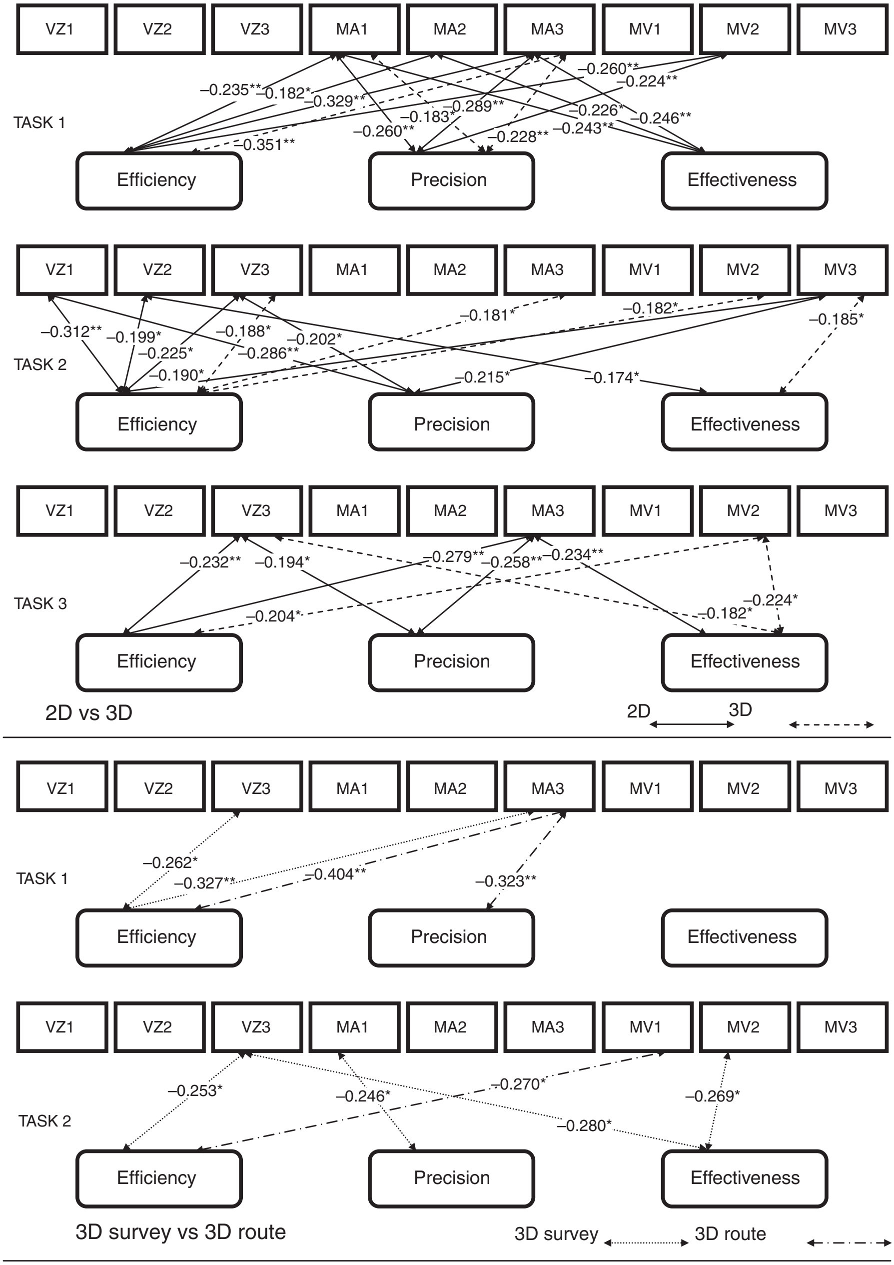

Figure 4.
Correlations among spatial abilities and information-seeking performances in 2D and 3D models

The operational approaches taken by participants when they were using the 2D interface were more diverse and exhaustive.

When participants conducted the first task on the 3D (survey+route) interface, MA3 ($r = -0.351$, $p = 0.000$) had a significant correlation with efficiency, and MA1

($r = -0.183$, $p = 0.039$), MA3 ($r = -0.228$, $p = 0.010$) had a significant correlation with precision. This suggests that users were operating under cognitive stress due to the 3D interface and had problems with slower operational time and less abilities. On the second task, users that have VZ3 ($r = -0.188$, $p = 0.035$), MA3 ($r = -0.181$, $p = 0.042$), and MV2 ($r = -0.182$, $p = 0.041$) performed differently on efficiency, and MV3 ($r = -0.185$, $p = 0.037$) on effectiveness, which indicates that as the participants became more familiar with an operation, they began adopting strategies like map expansion, word memorization, and comparing landmark icons to increase their speed, and comparing path patterns for effective searching. On the third task, participants performed differently on efficiency ($r = -0.204$, $p = 0.021$) and effectiveness ($r = -0.224$, $p = 0.011$), in accordance with their MV2 (Building Memory Test) ability, and effectiveness ($r = -0.182$, $p = 0.040$) with VZ3 (Surface Development Test), which suggests that users began to expedite information seeking by using landmark icons in the information space, and expanding thematic map once they got familiar with the operations. On 3D interfaces, users appeared to be experiencing cognitive overload, because they did not experiment with a broad range of cognitive abilities, as they did on the 2D interface, to perform the task.

On the 2D-extended and both 3D interfaces, for Task 1, only ability MA3 was significantly correlated to efficiency and precision. Given these results, we can conjecture that regardless of which interface the users used, they were able to achieve completion of the tasks by memorizing the meanings of words (tasks), prefixes, and suffixes. The level familiarity they attained with these words (tasks) lead to their choosing different icons. Users with a higher MA3 score spent less time on the tasks and had fewer incorrect searches. Effectiveness influences various operational trials, and the different approaches employed by users influence effectiveness. Perhaps that explains why MA3 is not significantly related to effectiveness.

The interfaces developed by this study utilized elements of the existing school curriculum that the children were already familiar with, which decreased their cognitive burden when they were attempting to understand the thematic structure. Children understood some parts of the interface structure, but appeared to be uncertain as to the placement of the information nodes. As a result, they adopted browsing as a strategy to find their exact target. They were then able to develop a search strategy (VZ3 in 2D, MV2 in 3D) for their next move. Children with limited vocabulary use the space efficiency (which allows for information accessibility), and precision, effectiveness (which influences information diagnosticity) as the most important criteria in their search. Children spent less time when using the 2D interface than they did when using the 3D interface, and applied an exhaustive approach. Thus the cognitive burden associated with the 3D interface outweighs its convenience for information accessibility; however, in terms of information diagnosticity, increased convenience outweighs the cognitive burden brought by a 3D interface.

The survey and route comparison in the 3D interface

In Table I, when comparing efficiency between the 3D-survey vs 3D-route interfaces, *t*-test results exposed significant differences over the three tasks (Task 1 $p = 0.006$, Task 2 $p = 0.001$, Task 3 $p = 0.000$). It appears that the children were able to operate the 3D-survey interface faster than the 3D-route interface. *t*-tests comparing differences in precision 3D-survey vs 3D-route interfaces revealed significant differences over the three tasks (Task 1 $p = 0.001$, Task 2 $p = 0.031$, Task 3 $p = 0.037$). *t*-Tests comparing effectiveness between the 3D-survey vs 3D-route revealed significant differences over the three tasks (Task 1 $p = 0.004$, Task 2 $p = 0.043$, Task 3 $p = 0.000$). It appears that the children were able to operate 3D-survey interfaces with more accuracy than the 3D-route interface. The 3D-survey interface was a more effective tool for children seeking information. This further confirms the speculation that children build their knowledge maps with the overview function on the 3D-survey interface, which helps them to effectively locate the database node and its group location. On the other hand, on a 3D-route interface, database groups are scattered loosely all over the interface, and because children are less skilled at figuring out group relationships, they have to go through a trial and error process before locating the database node. This process resulted in lower effectiveness.

Figure 4 shows that users can jump directly between different functions on the 3D-survey interface; they aren't restricted to linear operations. In Task 1, MA3 ($r = -0.327$, $p = 0.008$) appears to be used to memorize task information, while VZ3 ability affects efficiency ($r = -0.262$, $p = 0.037$). In Task 2, VZ3 affects efficiency ($r = -0.253$, $p = 0.044$) and effectiveness ($r = -0.280$, $p = 0.025$). On a 3D-survey interface, users appeared to experience information processing overload when too much information and too many functions were shown at one time; therefore, users were inclined to repeatedly expand (VZ3) the thematic map to process comparisons. In addition, users made use of MA1 (memory of object) at $r = -0.246$, $p = 0.050$, for precision, and MV2 (icon as landmark) at $r = -0.269$, $p = 0.032$, for effectiveness, thereby setting the anchor point in their mind map, implying that users still relied on expanding the information to figure out the structure behind the interface and the profile of sitemap. MA3 affects efficiency ($r = -0.404$, $p = 0.001$) and precision ($r = -0.323$, $p = 0.010$), and is used for memorizing the first task on the 3D-route interface when users lack knowledge of structural direction. Under these conditions, users mainly rely on trial and error methods, simply clicking on information nodes to confirm the theme and build a mind map. Only a small amount of information is displayed at one time in 3D-route interface, so information processing overload is unlikely. Users who had good cognition ability for figuring out icon appearance MV1 ($r = 0.270$, $p = 0.033$) employed good efficiency on the second task. For Task 3, students using the 3D-survey and 3D-route interfaces displayed no significant correlation between performance and abilities as measured by the FRCT.

The disparate performances on different information visualization interfaces in children with the same levels of ability is worth further discussion, especially as it pertains to their visual operation procedures and cross-memory operations. The purpose of an overview is to elevate the user from a 2D (egocentric) to a 3D (exocentric) view, allowing them to observe the structure of the information space and the placement of the icons that represent the information nodes. We discovered that improving operation of information visualization interfaces is a gradual process; participants improve then regress, and competency is built step by step. An overview is a dynamic procedure that requires the cross-operation of spatial perception and memory. Human beings rely on different types of intuition when they are faced with different interface features (survey, or route); some like to approach new information from a broad perspective (VZ3) while others like to approach from a micro-perspective (MV1).

The active acquisition of familiarity with a new information space allows the user to interact, explore and change information space content. A well-established principle of human memory is that it is often easier to recognize a word or name (a receptive task) than it is to think of the word or name (an expressive task). Using MA3, information can be memorized and compared with user perceptions. The user then analyzes the information and decides what to do next. Information visualization is useful for presenting cues in a visualized form, and the cue might integrate with the user's existing understanding of the distance characteristics of the 3D or 2D world.

The integration involved in maintaining a coherent mental picture of an evolving situation suggests that an effective overview not only broadcasts information but also integrates multiple pieces of information. Users utilized expansion, memory of object, and landmark, in 3D-survey, to improve effectiveness on the second task, showing that multiple abilities are involved when analyzing information space. Presumably the overview function helped users create an overall image of the information space, and as the cognitive burden was decreased on Task 2, users were able to the explore information space with other methods. MV1 (icon appearance) is used for the second task on the 3D-route interface to find the cues that can help a user reduce the time they spend searching. Patterson *et al.* (2001) proposed that a task is always memory- and comparison-oriented in the beginning. Later, when using different interfaces to complete different tasks, users will utilize diverse abilities and adopt strategies to work with memory and build up an accurate mind map. At this time, information visualization is useful in ruling out competing hypotheses or uncertain search results. However, since spotting useful results counts as a part of decision-making, this process may be affected by the characteristics of the 2D or 3D information space in use. An overview appears to serve as an index in the 3D information space. Users are able to leap from node to node or slowly improve their knowledge of the content of the database, and thereby connect the database to their inner indexes for further reference.

Conclusions and suggestions

This research used statistical analysis and comparisons to explore the development of 3D graphic searching interfaces for children. We explored how to turn a 2D interface into a 3D interface, developed a virtual interface for a children's digital library, and examined the information seeking and way-finding behavior exhibited by children as they navigated that library. The design of the interface focussed on a 3D virtual space, icons, and icon placement. The results of this experiment reveal that children perform differently on different interfaces, and there are gaps between the levels of efficiency, precision and effectiveness that they attain when operating the interface. Users appeared to experience less cognitive burden on a 2D interface than on its 3D counterpart. Users operated faster on the 3D-survey interface but encountered cognitive burden at a primary phase. They operated slower and showed fewer signs of cognitive burden on the 3D-route interface. Users adopted different abilities when constructing mind maps of the different interfaces. Users utilized an exhaustive approach in which they applied all applicable abilities on the 2D interface, while on the 3D interface they adopted a focussed approach. Children performed better on the 3D virtual interface in information seeking when they employed an overview navigation strategy, particularly when compared with a route navigation strategy. This suggests that providing children with survey knowledge about the whole system will assist them in their information-seeking tasks.

The prototype developed by this research was designed for children searching virtual spaces, and can bring together the study of human interest in an interface and information classification and retrieval. It can also be seen as a new method of testing the patterns associated with children's information-seeking behaviors. The results can be useful to those trying to make learning software more inviting. The research results can be employed to construct a suitable virtual digital library interface for children. Suggestions for further research are as follows.

The special ability of every child is different. Future digital library interfaces might provide different virtual space features for children to choose from. The individual user's history of search behavior was not considered. Qualitative data and experiential analysis would allow us to gain a more in depth understanding of search behavior. It may also help us to better understand the way children use digital resources and develop our understanding of their information-seeking behavior when using virtual interfaces. Further understanding would make it possible to construct an interface to meet their needs. All three tasks in this experiment only required the child to choose one icon from the existing documents; therefore, the children didn't necessarily follow the sequence of information. It may be that this caused poorer performance when they were using the 3D-route interface. As a result, further work is needed for appropriate task design.

References

Beheshti, J. (2012), "Virtual environments for children and teens", in Eichenberg, C. (Ed.), *Virtual Reality in Psychological, Medical and Pedagogical Applications*, InTech, Rijeka, pp. 271-286. doi: 10.5772/51628.

Bilal, D. (2005), "Children's IS and the design of digital interfaces in the affective paradigm", *Library Trends*, Vol. 54 No. 2, pp. 197-208.

Bilal, D. and Kirby, J. (2002), "Differences and similarities in info-seeking: children and adults as web users", *Information Processing and Management*, Vol. 38 No. 5, pp. 649-670.

Borlund, P. and Dreier, S. (2014), "An investigation of the search behaviour associated with Ingwersen's three types of information needs", *Information Processing and Management*, Vol. 50 No. 4, pp. 493-507.

Danielson, D. (2002), "Web navigation and the behavioural effects of constantly visible site maps", *Interacting with Computers*, Vol. 14 No. 5, pp. 601-618.

Downs, R.M. and Stea, D. (1973), "Cognitive maps and spatial behavior: process and products", in Downs, R.M. and Stea, D. (Eds), *Image and Environment: Cognitive Mapping and Spatial Behavior*, Aldine, Chicago, IL, pp. 8-26.

Gossen, T. and Nürnberger, A. (2013), "Specifics of information retrieval for young users: a survey", *Information Processing and Management*, Vol. 49 No. 4, pp. 739-756.

Greene, S., Marchionini, G., Plaisant, C. and Shneiderman, B. (2000), "Previews and overviews in digital libraries: designing surrogates to support visual information seeking", *Journal of American Society for Information Science*, Vol. 51 No. 4, pp. 380-393.

Henry, J.A.G. and Polys, N.F. (2012), "The effects of immersion and navigation on the acquisition of spatial knowledge of abstract data networks", *Procedia Computer Science*, Vol. 1 No. 1, pp. 1737-1746.

Hornbæk, K. and Hertzum, M. (2011), "The notion of overview in information visualization", *International Journal of Human-Computer Studies*, Vol. 69 No. 7, pp. 509-525.

Hourcade, J.P. (2007), "Interaction design and children", *Foundation and Trends in Human-Computer Interaction*, Vol. 1 No. 4, pp. 277-392. doi: 10.1561/1100000006.

Hutchinson, H.B., Druin, A. and Bederson, B.B. (2007), "Supporting elementary-age children's searching and browsing: design and evaluation using the international children's digital library", *Journal of the American Society for Information Science and Technology*, Vol. 58 No. 11, pp. 1618-1630.

Kitchin, R.M. (1997), "Exploring spatial thought", *Environments and Behavior*, Vol. 29 No. 1, pp. 123-156.

Koshman, S. (2006), "Visualization-based information retrieval on the web", *Library and Information Science Research*, Vol. 28 No. 2, pp. 192-207.

Kosslyn, S.M. (1987), "Seeing and imagining in the cerebral hemispheres: a computational approach", *Psychological Review*, Vol. 94 No. 2, pp. 148-175.

Lynch, P.J. and Horton, S. (2009), *Web Style Guide, 3rd Edition: Basic Design Principles for Creating Web Sites*, 3rd ed., Yale University Press, New Haven, CT and London.

Messinger, P.R., Stroulia, E., Lyons, K., Bone, M., Niu, R.H., Smirnov, K. and Perelgut, S. (2009), "Virtual worlds-past, present, and future: new directions in social computing", *Decision Support Systems*, Vol. 47 No. 3, pp. 204-228.

Münzer, S., Zimmer, H.D., Schwalm, M., Baus, J. and Aslan, I. (2006), "Computer-assisted navigation and the acquisition of route and survey knowledge", *Journal of Environmental Psychology*, Vol. 26 No. 4, pp. 300-308.

Nielsen, J. (2000), "Jakob Nielsen's alertbox: is navigation useful?", available at: www.useit.com/alertbox/20000109.html (accessed 27 July 2015).

Patterson, E., Roth, E. and Woods, D. (2001), "Predicting vulnerabilities in computer-supported inferential analysis under data overload", *Cognition, Technology and Work*, Vol. 3 No. 4, pp. 224-237.

Risden, K., Czerwinski, M.P., Munzner, T. and Cook, D.B. (2000), "An initial examination of ease of use for 2D and 3D information visualizations of web content", *International Journal of Human-Computer Studies*, Vol. 53 No. 5, pp. 695-714.

Shenton, A.K. and Dixon, P. (2004), "Issues arising from youngsters' information-seeking behavior", *Library and Information Science Research*, Vol. 26 No. 2, pp. 177-200.

Tory, M., Sprague, D.W., Wu, F., So, W.Y. and Munzner, T. (2007), "Spatialization design: comparing points and landscapes", *IEEE Transactions on Visualization and Computer Graphics*, Vol. 13 No. 6, pp. 1262-1269.

Ware, C. (2013), *Information Visualization: Perception for Design*, 3rd ed., Morgan Kaufmann, Waltham, MA.

Westerman, S. and Cribbin, T. (2000), "Mapping semantic information in virtual space: dimensions, variance and individual differences", *International Journal of Human-Computers Studies*, Vol. 53 No. 5, pp. 765-787.

Westerman, S.J., Collins, J. and Cribbin, T. (2005), "Browsing a document collection represented in two-and three-dimensional virtual information space", *International Journal of Human-Computer Studies*, Vol. 62 No. 6, pp. 713-736.

Wu, K., Tang, Y. and Tsai, C. (2014), "Graphical interface design for children seeking information in a digital library", *Visualization in Engineering*, Vol. 2 No. 5, pp. 1-14.

Zhang, X. (2008), "A multiscale progressive model on virtual navigation", *International Journal of Human-Computer Studies*, Vol. 66 No. 4, pp. 243-256.

About the authors

Kochiu Wu is an Associate Professor in the Department of Interaction Design, National Taipei University of Technology, Taiwan. He has professional practices of library design, and media communication. His research focusses on Human-computer interface design, IS behavior and cognition differentiation of media. Associate Professor Kochiu Wu is the corresponding author and can be contacted at: kochiuwu@mail.ntut.edu.tw

Hung-Chun Chen is an Interactive Programmer at the Compal Electronics, a leading manufacturer of notebook PCs, LCD products, and smart device. He graduated from the National Taipei University of Technology, with master degrees in Interactive Media Design in 2012. He is interested in Human-computer interface design.

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1. WuKo-Chiu Ko-Chiu Wu Ko-Chiu Wu is an Associate Professor in the Department of Interaction Design, National Taipei University of Technology, Taiwan. He has professional practices of library design, and media communication. His research focusses on human-computer interface design, IS behavior, and cognition differentiation of media. ChenHung-Chun Hung-Chun Chen Hung-Chun Chen is an Interactive Programmer at the Compal Electronics, a leading manufacturer of notebook PCs, LCD products and smart device. He graduated from the National Taipei University of Technology, with master degrees in Interactive Media Design in 2012. He is interested in human-computer interface design. Department of Interaction Design, National Taipei University of Technology, Taipei City, Taiwan . 2016. How curiosity and uncertainty shape children's information seeking behaviors. *Library Hi Tech* **34**:3, 549-564. [Abstract] [Full Text] [PDF]