Design and Implementation of Spatial Navigation Transfer Game for Examining Transfer of Learning

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Abstract
Learners continuously shape and reshape their knowledge base, which allows them to generalize their learning to novel contexts and solve novel problems. Irrespective of the academic domain, it is important to provide students with a variety of opportunities to apply their learning across multiple contexts, thus increasing self-awareness and autonomy, and enhancing transfer. Understanding the cognitive processes underlying transfer and developing instructional strategies that could be used to enhance transfer across various contexts is an important, yet challenging educational issue. This paper discusses the design features of a Spatial Navigation Transfer (SNT) game, which was developed by the researchers of this study to examine problem solving and transfer of learning in virtual environments. The SNT game was piloted with six graduate students at a private, four-year university located in the northeast of the US. This paper presents preliminary findings from the pilot study and implications for instruction and instructional design for enhancing transfer of problem solving skills within higher education.

Keywords: transfer of learning, game design, problem solving, spatial navigation

Introduction

In adult education, being able to effectively problem solve and transfer problem solving skills across multiple contexts, including virtual and real-world contexts, is vital. As noted by Broad (1997), acquiring the necessary skills to transfer is especially critical for adult learners since they are often expected to effectively and continuously apply knowledge and skill gained during learning activities to their jobs or other organizational and community responsibilities. Furthermore, research by Hung (2013) pointed out that employees are often required to be critical thinkers, independent problem solvers, and lifelong learners to be able to stay competitive in a job market. Therefore, college students or workplace trainees are in need for acquiring skills of applying and transferring knowledge across different settings.

Based on one of its broader definitions, transfer is "a term that describes a situation where information learned at one point in time influences performance on information encountered at a later point in time" (Royer, Mestre, & Dufresne, 2005, p. vii). According to the National Research Council (2013), transfer can be characterized in terms of deeper learning which is described as the process of taking what was learned in one context and applying it to new contexts. Deeper learning can lead to development of expertise within a domain. It results in acquisition of transferrable knowledge, which includes not only content but also procedural knowledge of how, when, and where to apply that knowledge.

Closely aligned with transfer research have been the investigations into the area of problem-solving transfer. According to Jonassen (1997), a problem is broadly defined as "an unknown that results from any situation in which a person seeks to fulfill a need or accomplish a goal" (p. 66). Problem solving transfer was characterized as an ability to use prior learning to solve problems that are different from those provided in the original instruction (Mayer, 1992). Among problem solving strategies, general problem solving has been widely researched as a strategy to enhance transfer (Youssef-Shalala, Ayres, Schubert, & Sweller, 2014). General problem solving strategies, such as simple heuristic, metacognitive strategies, and multistep problem solving routines, transcend specific domains and, therefore, can be applied in a variety of contexts, thus promoting transfer (Youssef-Shalala et al, 2014).

Despite the significant role of problem solving transfer in human learning, enhancing student abilities to effectively transfer newly learned knowledge and skills has always been one of the most challenging problems in education (Kaieser, Kaminski, & Foley, 2013; Haskell, 2000). This can be explained by the complexity and the multidimensionality of the transfer phenomenon. There has been a plethora of research on the factors affecting problem solving transfer. Research shows that changes in task procedure (e.g., addition of a secondary task) (Healy, Wohldmann, Parker, & Bourne, 2005), context (Kole, Healy, Fierman, & Bourne, 2010), task stimuli (Bourne Jr, Healy, Pauli, Parker, & Birbaumer, 2005) or required responses (Healy, Wohldmann, Sutton, & Bourne Jr, 2006) may influence learner performance on the transfer task. Another study, that used the classical Tower of Hanoi and two other analogous problems solving tasks, showed that familiarity of the instructions or the cover story that was used in the learning task influenced the degree to which the participants transferred their learning to new tasks (Kole, Snyder, Brojde, & Friend, 2015).

The purpose of this paper is to discuss the design and development of a Spatial Navigation Transfer (SNT) game by the researchers of this study to examine problem solving and transfer of learning in virtual environments. The design and implementation of the SNT game was guided by Cognitve Load Theory used as a broader theoretical framework.

Theoretical framework

Cognitive Load Theory (CLT), which was developed in the 1980s, informs instructional design by proposing instructional strategies based on human cognitive architecture (Paas, Renkl, & Sweller, 2003; Sweller, 1988). CLT helps to address some essential educational issues, such as stimulating learners' cognitive resources to enhance learning, handling complex learning tasks, and dealing with learners of different expertise levels (Kirschner, Sweller & Kirschner, 2018, Van Merriënboer, & Sweller, 2010). CLT becomes especially vital when dealing with complex learning tasks which can exert a heavy cognitive load on the memory system (Van Merriënboer, Kester, & Paas, 2006).

It is known that unlike the long-term memory, which is characterized by infinite memory capacity, working memory is significantly limited. Working memory was defined as "a limited- capacity system for temporary storage and manipulation of information for complex tasks such as comprehension, learning, and reasoning" (as cited in Goldstein, 2014, p.133). CLT is based on the assumption that human working memory has limited capacity when dealing with new information and can hold five to nine information elements (Miller, 1956). The number of new information elements that can be processed actively at the same time ranges between two and four (Van Merriënboer, & Sweller, 2010). Working memory can process information for only a few seconds. Moreover, after nearly 20 seconds almost all information is lost unless it is maintained by repeated rehearsal (Van Merrienboer & Sweller, 2005).

Working memory load can be influenced by three types of cognitive load, namely the intrinsic cognitive load, extraneous cognitive load, and germane cognitive load. Intrinsic cognitive load is characterized by the intrinsic nature of the task to be learned, extraneous cognitive load is the way in which the tasks are presented to the learner, and the germane load is described in terms of the cognitive resources that learners use to learn something (Van Merriënboer & Ayres, 2005).

Well-Defined and Ill-Defined Problems

Structurally, problems can be classified into well-defined and ill-defined problems (Schraw, Dunkle, & Bendixen, 1995) or well-structured and ill-structured problems (Jonassen, 1997; Schraw et al., 1995). According to Kitchener (1983) well-defined problems are those which have "absolutely correct and knowable solutions", while ill-defined problems are those "for which there are conflicting assumptions, evidence, and opinion which may lead to different solutions". (p. 223) Mayer and Wittrock (1996) pointed out that for well-defined problems, the allowable operations to be performed to reach from the given state to the goal are known to the problem solver. For instance, a computational problem such as 3 x 15=? is well defined since the given state is 3x15, the goal state is a numeric answer, and the allowable operation is multiplication. In contrast, in ill-defined problems, the given state, the goal state, and the allowable operations are not clear to the problem solver (Mayer & Wittrock, 1996). An example of an ill-defined problem is to write an essay about how to prevent global warming. Unfortunately, many educational materials contain well-defined problems, while most problems outside the educational context are ill-defined (Mayer & Wittrock, 1996).

Spatial Navigation Transfer Game

The SNT game was a web application built using modern technologies and consisted of an Express/NodeJS web server and a single interactive HTML page on the front that contained the JavaScript-based game engine and was served as a static resource. The engine was specifically developed for this game and once the user opened the page with a browser, it started running and took over. It made extensive use of jQuery, and was in charge of downloading, showing and manipulating various elements of the game such as the dialog boxes, instruction pages, and the actual game. Moreover, the engine recorded user inputs and interactions, game states and results, and uploaded them to the server.

The SNT game was designed and developed using Cognitive Load Theory as a broader conceptual framework. The game consisted of two well-structured analogical spatial navigation problems and two ill-structured analogical problems. The well-structured problems represented two analogous scenarios: School Bus and Ambulance. Each of the two well-defined spatial navigation problem scenarios included nine analogical tasks of three levels of difficulty: low, medium, and high cognitive load tasks.

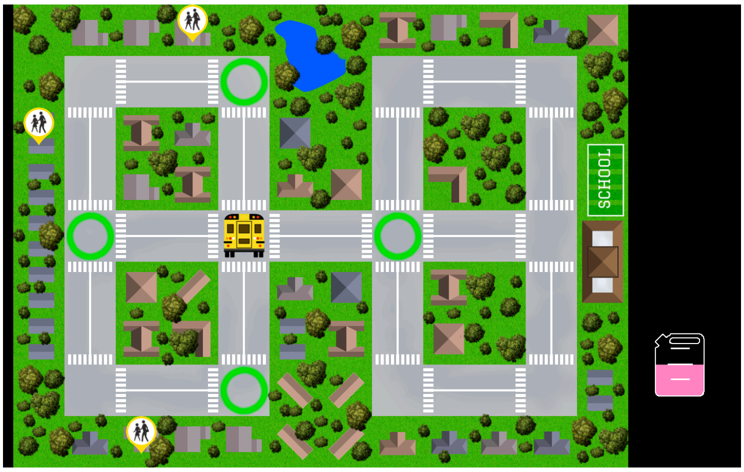

Figure 1. School Bus Scenario.

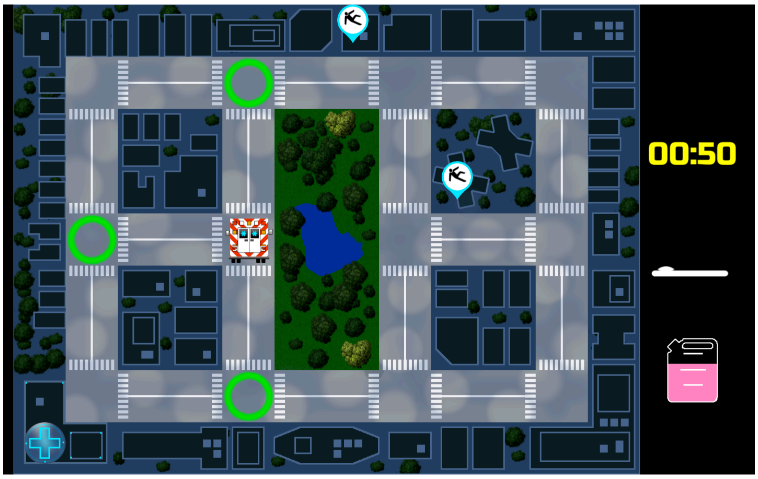

Figure 2. Ambulance Scenario.

In the School Bus scenario, the player assumed the role of a school bus driver whose task was to navigate the game map to collect students from different locations and drive them to school. In the ambulance problem, the player assumed the role of an ambulance driver who received calls from patients and had to collect them from different locations on the game map and take them to the hospital. The difficulty level of each task for both problems was defined by the number of constraints such as a limited amount of fuel, limited amount of time, limited number of seats, and increasing traffic

In addition, the game provided the players with a tutorial analogous to the well-structured problem scenarios. The purpose of the tutorial was to introduce the players to the game structure and techniques. The tasks within each level were preceded by detailed instruction pages containing the description of the tasks and the type of constraints contained in the tasks.

The ill-structured problems consisted of two analogical scenarios in which the subjects were asked to generate as many solutions as possible. Both tasks were untimed. The problems were of two complexity levels, namely a simple everyday problem scenario and a more complex generic problem scenario.

Pilot Study

The SNT game was piloted with six graduate students at a private, four-year university located in the northeast of the US. The results indicated an overall decrease in reaction time and total time spent on SNT game tasks from week one to week two of the experiment. The analysis of the participant behavioral data and oral feedback collected during the pilot study allowed for modification of certain design features of the game. Some of these modifications included clarifying the instructions and editing the tasks within each difficulty level.

Currently, the SNT game is being implemented in an experimental study with 27 participants. The study uses a within-subject repeated measures experimental design with a neuroimaging tool called functional near infrared spectroscopy (fNIRS) to measure mental workload during the SNT game play. The main purpose of the experiment was to investigate neurocognitive, behavioral, and task variables involved in general problem solving transfer.

Conclusion

This research was significant since it examined transfer of general problem skills by applying analysis at multiple levels, namely neurocognitive, behavioral, and task levels. Investigating neurocognitive, behavioral, and task-related variables affecting problem solving transfer is essential in understanding the complex and multidimensional nature of the transfer phenomenon. Understanding the neural mechanisms of transfer is closely linked to knowledge of learning, human memory, reasoning, and problem solving. Investigation of the multiple factors affecting learning and transfer of problem solving at the brain level creates multiple opportunities for differentiated instruction characterized by brain-friendly, learner-centered, and customizable learning experiences.

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