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When does higher degree of interaction lead to higher learning in visualizations? Exploring the role of 'Interactivity Enriching Features'

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ABSTRACT

Interactive visualizations are being used extensively for effective teaching and learning. Higher degree of interaction in visualizations improves comprehension and leads to deeper learning. However, some research studies have reported ambiguous, inconclusive results in terms of learning benefits of interactive visualizations. The conditional results in such studies suggest some additional features to be instrumental in assisting learners in deriving benefits of interactivity in visualizations. We refer to these features as '*Interactivity Enriching Features*'. This study examines how degree of interaction of the user with the visualization affects learning outcome. The study proposes how interactivity in visualizations can be enriched by offering apt affordances and evaluates what additional features could make learning from interactive visualizations more effective at the same degree of interaction. The study has been carried out in the context of a course on Signals and Systems in Electrical Engineering on second year engineering students ($N = 134$). The subjects were assigned to one of the four conditions: a Non-Interactive Visualization, an Animation, a Simulation, and an Interactivity Enriched Visualization. The dependent variable was test-score for 'Understand conceptual knowledge', 'Understand procedural knowledge' and 'Apply procedural knowledge' categories. The research findings indicate that, i) different degrees of interaction are required for learning different types of knowledge and ii) interactive visualization could not deliver its learning benefits unless it was augmented by '*Interactivity Enriching Features*' in the form of appropriate affordance for variable manipulation, especially for higher learning outcomes. This research study contributes towards the design of educationally effective interactive visualizations.

1. Introduction

Use of computer-based interactive visualization is being advocated and suggested extensively as an instructional aid. It is being used by, right from elementary level school students up to university students, in a diverse range of topics. They have been used in the teaching-learning of elementary level science concepts (Barak, Ashkar, & Dori, 2011), as well as complex concepts or processes in engineering and allied courses (Boucheix & Schneider, 2009; Lattu, Meisalob, & Tarhioc, 2003; de los Santos Vidal, Jameson, Iskander, Balcells, & Catten, 1996; Wang, Vaughnb, & Min Liu, 2011). Interactive visualizations, in particular, have been extensively used in the learning of science and engineering domains. Specifically, in engineering education, they have been recommended to comprehend phenomenon that are dynamic with respect to time, space or any other variable (Aleksandrova & Nancheva, 2007; Engin, 2006; McManus & Rebentisch, 2008; Kühl, Scheiter, Gerjets, & Gemballa, 2011). Interactive visualizations allow learners to interact with the educational content (Chaturvedi & Osman, 2006; Park, Lee, & Kim, 2009; de los Santos Vidal et al., 1996). The interaction in such visualizations is said to occur when some response is elicited from the learner and in turn, the visualization is able to respond to the learner's input. The quality of such interaction has been referred to as interactivity (Sedig & Liang, 2006).

Degree of interaction in interactive visualizations can be varied by varying the amount of learner control. Degree of learner control may vary from viewing still images up to manipulating content and further up to creation of visualizations. Animation and simulation have been

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two common variants of interactive visualizations offering varying degree of interaction. While an animation offers pace or direction control of the animated educational content, a simulation offers opportunities to learner to explore interactions among dynamic variables by allowing manipulation of the educational content (Lin & Atkinson, 2011; Park et al., 2009). The degree of interaction plays an important role in the learning process (Schulmeister, 2003). In addition to giving control of the information delivery (as in animation) in visualization, when the learner is also allowed to manipulate its content (as in simulation), higher level of thinking is expected to happen (Plass, Homer, & Hayward, 2009) and leads to deeper learning in terms of conceptual and analytical thinking (Stieff & Wilensky, 2003; Wu, Krajcik, & Soloway, 2001).

Interactive visualizations have been known to offer several benefits. By providing opportunities to practise 'what-if' scenarios, the interactivity in the visualizations fosters learners' analytical skills. The learning benefits derived from their use have covered a range of abilities and skills, such as, explanation ability, comprehension, ability to correlate scientific concepts, learning of conceptual and procedural knowledge, process of skill acquisition, building of mental models, as well as increased learners' engagement (Kriz & Hegarty, 2007; Rutten,Van Joolingen, & Van der Veen, 2012; Schwan & Riempp, 2004). However, in spite of strong empirical results of learning benefits, it cannot be claimed unanimously that interactive visualizations improve learning, as some studies have not produced convincing evidence for demonstrating improvement in learning (Hansen, 2002; Domagk, Schwartz, & Plass, 2010; Moreno & Valdez, 2005). Thus, whether higher degree of interaction in visualization always leads to effective learning has always been a stimulating research question.

While exploring the relevant literature to answer the above given question, it is observed that, many experimental results related to learning from interactive visualizations have been conditional and the learning benefits were ensured only in the presence of additional conditions (Hansen, 2002; Liang, 2006; Lin & Atkinson, 2011; Spanjers, Van Gog, Wouters, & Van Merriënboer, 2012; Tversky, Morrison, & Betrancourt, 2002). The mixed results from empirical studies suggest that more research is needed to explore, 'what influences learning from interactive visualizations?' (Rey, 2011). The conditional nature of experimental results suggest that, not just the given degree of learner control, but, some additional features must have been pivotal in assisting learners in deriving learning benefits of interactivity from interactive visualizations. We propose to refer to such features as '*Interactivity Enriching Features*', as we anticipate that these features would enrich the quality of interactions. These are visualization features as an affordance to users, embedded in interactive visualization. It is expected that users' physical interaction with these features will lead to the improvement in learning from interactive visualizations.

While affordance refers to all "action possibilities" latent in the environment (Gibson, 1977), in the context of interactive learning environment, it refers to the way interactive visualization offers its usage cues and indicates what sorts of operations can be performed on it (Sedig & Sumner, 2006). As affordances relate to both; the degree and quality of interaction, different affordances offered by varying degree and/or quality of interaction, provide different learning opportunities to learners. The real potential of interactive visualization is achieved when these learning opportunities are used intentionally and effectively. To facilitate this aspect, we used two '*Interactivity Enriching Features*' in the form of affordance. In this study, we demonstrated how the said affordances qualified as '*Interactivity Enriching Features*' and led to effective learning by effectively utilizing the inherent learning potential of interactive visualizations.

The study has been carried out in the context of a course on Signals and Systems in Electrical Engineering. Signals and Systems is one of the foundation courses in the field of Communication and Signal Processing. Numerous interactive visualizations in the form of Java applets, MATLAB/Simulink® models, and LabVIEW models are available and are frequently used as a learning aid (Guan, Zhang, & Zheng, 2009; Kehtarnavaz, Loizou, & Rahman, 2008). Various resources containing interactive visualizations such as SYSTOOL, SSUM, J-DSP Tutor, and 'Interactive learning resources for Signal, Systems and Controls' (Crutchfield & Rugh, 1997; Rabenstein, 2002; Shaffer, Hamaker, & Picone, 1998; Spanias, Chilumula, & Huang, 2006; Sturm, & Gibson, 2005) have been recommended for learning of Signals and Systems. The need to visualize abstract concepts, to understand multiple representation forms of these concepts, and to apply multiple computational steps (Nelson, Hjalmarson, Wage, & Buck, 2010) are some of the reasons that have made interactive visualizations prevalent in the Signals and Systems teaching community.

One of the motivations for this study was to investigate the highly intuitive and well-accepted notion of 'higher degree of interactions in visualizations leads to better learning'. This study was set with the purpose of examining whether higher degree of interaction and the affordances in the form of '*Interactivity Enriching Features*' lead to effective learning. Firstly, we hypothesized that, higher degree of interaction in interactive visualizations would lead to better learning of conceptual and procedural knowledge. Another motivation of this study was to evaluate what additional features could make learning from interactive visualizations more effective at the same degree of interaction. Thus, we also hypothesized that, at the same degree of interaction, the interactive visualizations with '*Interactivity Enriching Features*' would be more effective for learning as compared to the interactive visualizations without such features. This study reported in this paper investigated, how degree of interaction and apt affordance contribute towards effective learning from interactive visualizations, especially while dealing with conceptual and procedural knowledge in the context of a course on Signals and Systems.

2. Review of related work

2.1. Interactivity in visualization

Visualization is "*the use of computer supported, interactive, visual representations of data to amplify cognition*" (Tory & Möller, 2002). Interactivity is the process of learner engagement with the content in the visualizations, in which the learners' behaviour depends on the action of the system, which in turn depends on the reaction of the learner, and so on (Domagk et al., 2010). Interactivity is not merely an interaction. While interaction refers to various kinds of actions initiated by a learner to interact with the different visualization features, interactivity is the quality or property of such interactions. Lower interactivity implies a behaviourist character of a learner, while higher interactivity leads to constructivist learning, such as discovery learning. The learning experience from interactive visualizations has been operationalized in the form of hierarchical nature of learner control being offered. While referring to this as 'level of interactivity', the author has defined six hierarchal levels of interactivity offering varying degree of possible interactions (Schulmeister, 2003). From a functional and qualitative perspective, interactivity has been organized in a hierarchical manner by number of researchers, in which, distinct levels of interactivity have been proposed by Bétrancourt and Tversky (2000), El Saddik (2001), Gao and Lehman (2003), Hanisch and Straβer (2005), Reichert and Hartmann (2004), Schulmeister (2003). While the number of levels in the hierarchy and nomenclature differ in each