Learners' strategies with multiple representations

Conference Item

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This empirical study investigated how varied instantiations of mathematical representations influenced learners' strategies. The analysis took into account gazes, utterances, actions and writings of 18 learners performing 3 tasks using static, dynamic, and interactive instantiations. Results show a variation in frequencies of strategies that the participants of the study employed for using multiple representations. This indicates that varying instantiations of multiple representations influences learners' strategies.

Introduction

How do varying instantiations of multiple computer-based representations influence learners' strategies for using those representations to solve tasks? That is: do different instantiations – "static" (non-moving, non-changing, non-interactive), "dynamic" (capable of animation through alphanumeric inputs), and "interactive" (directly manipulable graphs) – influence behaviour with otherwise similar representations? These different types of instantiation have been claimed to influence cognitive processing. Split-attention effects, where a particular representation, for example, can be animated whilst other representations are static, may influence learners' attention [1]. Multiple representations presented in a computer environment have been found in some cases to help and in others to hinder the learning process (e.g. [2]). Learners have also been found to experience failure to link insights drawn from one representation to another representation [3]. The study described here investigated learners' strategies with multiple mathematical representations presented in different instantiations.

Study design

Eighteen participants, with A-level Mathematics qualifications or higher, were given three tasks involving multiple mathematical representations (*algebraic*, *numeric* and *graphic*) instantiated in different ways (*static*, *dynamic* and *interactive*). A rotational design was adopted in randomly assigning tasks and instantiations. The data collection consisted of 1) pre-task interview and a 5-minute trial task; 2) completion of the tasks (30 minutes each) with the participants asked to "think-aloud"[4], and 3) a retrospective interview in which participants were asked to talk the researcher through what they did whilst viewing a video of their activity. The tasks were: 1) to make inferences about the solutions of a cubic function and the new solution when rotated 180 degrees about a point on the x-axis ("*root task*"); 2) to make inferences about the midpoints of the chords drawn between two points on any cubic function ("*chordal task*"); and 3) to make inferences about the boundaries of the regions that can be determined according to the number of tangents that can be drawn through a point in that region of a cubic function ("*tangent task*").

Digital approaches to capturing, coordinating and analysing what the learners said, did, saw, and wrote was recorded digitally and time-stamped so that it could be viewed and analysed as a coordinated whole. The techniques take advantage of the latest analysis software that facilitates synchronisation and encoding of multiple video feeds, eye gazes, handwriting, and verbal transcripts (Figure 1). Utterances and action were captured, using a digital camcorder, as an indication of thought processes that might be occurring; real-time writing and sketching were captured with a tablet PC, to identify additional representations being used; and gazes were captured using an unobtrusive eye-tracking device, so as to identify objects of attention [5].

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Figure 1: *Examples of action, writing, screen and gaze videos*

Data analysis

The analysis software showed 'saccades', traces of the paths that the eye took across the screen, and 'fixations', records of where the eyes lingered on a part of the screen. By superimposing saccades and fixations on the screen activity, the researcher can see shifts of learners' attention. When participants' speech, gestures and writing were integrated into the analysis, it was possible to identify a range of strategies for using multiple representations.

A range of '*representation-specific*' strategies (how the learners viewed and manipulated the representation) were identified: 1) algebraic-chunking 2) algebraic-graphic 3) algebraic-manipulation 4) graphic-algebraic 5) graphic-numeric 6) graph-wise 7) numeric-algebraic 8) numeric-trial and 9) point-wise. Further qualitative analysis identified five '*imagining*' strategies (how the learners used mental visualisations as far as can be detected from the data): 1) gaze-drawing 2) pen-drawing 3) gestural-drawing 4) mental-drawing and 5) mouse-drawing. Examples are given in Table 1.

Table 1: Examples of coding into representation-specific and imagining strategies

Strategy	*Characterisation*	*Example*
Algebraic-graphic	Modifies an equation to compare successive graphs	"I'm changing the coefficient to see what happens…" [attention switches to graph]
Graphic-algebraic	Links the graphic to algebraic expressions	"I think it has something to do with the function itself…" [attention switches to algebraic representation]
Gaze-drawing	Imagines or predicts a behaviour of a graph visually	"I'm trying to imagine where the points are" [gaze plot shows eyes generating a curve]
Mouse-drawing	Imagines or predicts a behaviour of a graph using the mouse	"This tends to move from here to here…" [mouse cursor indicates the movement]

Figure 2 shows the number of participants (n = 18) who used imagining strategies graphed by instantiation across the three tasks. Regardless of the task, only 1 of 18 (or 6%) participants used a gaze-drawing strategy when the instantiation was interactive compared to 10 of 18 (or 56%) when dynamic and to 14 of 18 (or 78%) when static.

Preliminary findings

The analysis is in line with the speculation of Larkin and Simon [6] that "mental images play a role in problem solving quite analogous to the role played by external representations" (p.97). The results also suggest that the strategies chosen vary from task to task, but that different participants use the same representation-specific strategies as each other when the task is the same. Among the further results, we found that by comparing participants' strategies for each instantiation, the participants spent more time using imagining strategies with static

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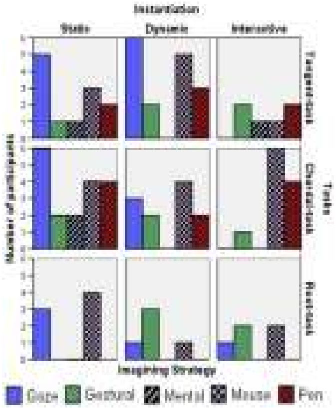

Figure 2: No. of participants using imagining strategies

instantiations than with dynamic or interactive instantiations. Investigating the strategies by task regardless of the instantiation, the root task did not elicit as many imagining strategies as the other two tasks. This result was then related to representation-specific strategies employed. It was found that there were more algebraic-related strategies for the root task in the dynamic instantiation than in the other two instantiations. Although we cannot make any strong claims about participants' performance, it was surprising to find that no one answered the chord task correctly. However, the common error made by the participants was to relate the task using a representation-specific point-wise strategy, a strategy utilising discrete points of a graphic representation, which did not appear when the instantiation was dynamic. One particular strategy found was a gaze-drawing imagining strategy (c.f. [7]), in which the participant imagines a behaviour of a graph using their eyes. However, when the instantiations are interactive, the participants do not appear to use a gaze-drawing imagining strategy. These results may provide some explanation of how interactivity helps or hinders learners' understanding of multiple representations.

Based on our findings, having multiple representations available to learners provides an opportunity to use representation(s) with which they are comfortable but nevertheless, the instantiation can draw the learners' attention to a useful representation. This approach has afforded some insights into the contradictions in the literature and offers real potential for explicating the finer relationships between representations, instantiations, and learner strategies.

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