SELECTING MULTIMEDIA INTERACTIONS TO BUILD KNOWLEDGE STRUCTURES

Wendy Doube
Monash University, Gippsland Campus
Churchill VIC 3842 Australia

Juhani Tuovinen
Batchelor Institute of Indigenous Tertiary Education
Batchelor NT 0845 Australia

Dale Shaffer
Lander University
Greenwood, SC 29649 USA

ABSTRACT
Two sets of multimedia learning materials were compared for their ability to promote learning of introductory computer programming. The first set of materials was a sequentially navigated multiple-screen multimedia application created according to well-established instructional design frameworks developed for the classroom or print materials. The second set was presented on a single screen designed in accordance with multimedia learning theory. The first set proved poorer for learning than standard laboratory session materials. The second set supported learning in novice learners to a greater degree than an equivalent set of print materials, the first set of multimedia materials, and the standard laboratory materials from the first experiment. The most apparent difference in the two sets of materials was that the second set aimed to reduce split attention by including only key information and by eliminating navigation between screens. The second set of materials also profited from increased content-related interactivity to simulate instructor-learner dialogue, thus elaborating declarative knowledge structures with procedural knowledge.

KEYWORDS
Multimedia, cognitive load, interactivity, split attention, programming

1. INTRODUCTION
The world of code can prove overwhelmingly abstract for novice computer programming students. Multimedia has the potential to allow learners to develop declarative knowledge structures with familiar concrete graphical examples before moving into the abstract. Multimedia interactions have the potential to allow introductory programming students to practice and self-test in a user-friendly environment, thus elaborating declarative knowledge with procedural knowledge before entering a possibly incomprehensible development environment (Anderson 1985, Anderson et al. 1990). With some notable exceptions (including Chandler and Sweller, 1992, Mayer 2001, Stasko et al 1997) learning from multimedia is largely uncharted with empirical studies. This paper makes an empirically based comparison of the learning outcomes from two multimedia learning applications for introductory computer programming undergraduates. The first application follows established instructional design principles, aiming to produce transfer of learning to unfamiliar situations. The second application follows the immature field of multimedia design principles, specifically aiming to reduce cognitive load from multiple visual media, while maximizing the benefits from simulated instructor-student dialogue. The comparison suggests that accepted and well-established instructional design guidelines may be confounded by characteristics of multimedia.
2. LEARNING FROM MULTIMEDIA

Multimedia is generally hailed as being beneficial for learning, at the very least because of its potential to engage and motivate the learner (Small 1997). However, controlled studies confirming its impact are not easy to find amongst multimedia learning literature describing theories such as multiple representation theory (Tegan, 1997). Meta-studies of controlled studies present contradictory viewpoints (Najjar 1998, Russell 1999). The current body of empirical research can be roughly categorized as media or interaction focused.

2.1 Multiple media

The main empirical research into the impact of one or more media on learning is based on cognitive load theory (Sweller & Chandler 1994) and dual-coding theory (Paivio 1986). The basic premise of cognitive load theory is that working memory can only accommodate a small amount of information for a very short time, and that reduced load on working memory will facilitate efficient transfer, storage and retrieval of information in long-term memory. Learning can be promoted either by reducing cognitive load or by expanding working memory. The aim of instruction is to reduce extraneous cognitive load imposed by the instructional environment, over and above the learning content. Mayer (2001) has applied cognitive load theory to multimedia learning, producing a set of instructional design principles specifically for use with multimedia learning applications. The significance of dual-coding theory when applied to cognitive load theory is that working memory can be expanded when verbal and visual channels are employed simultaneously.

2.2 Interactivity

A significant proportion of multimedia research literature into interactivity establishes taxonomies (Sims 1996) or offers prescriptions for multimedia instructional design (Oliver 1996). Laurillard’s (1993) pivotal research into the nature of multimedia learning environments relies on phenomenology as a research methodology to both establish a taxonomy of multimedia forms and to prescribe instructional best practice for use with those forms. According to this framework, best practice is defined as one-to-one learner-instructor dialogue. By implication, a multimedia form’s effectiveness in promoting learning depends on its ability to simulate learner-instructor dialogue, and thus align the learner’s perception of the knowledge with the instructor’s.

Instructor-learner dialogue can be decomposed into single learning interactions, each consisting of three components: 1. Presentation of information; 2. Learner response; 3. Feedback (Reeves 1998). Within a broader taxonomy beyond the scope of this paper, graphical user interface interactions, such as ‘type-in boxes’ and ‘drag and drop object’, can be mapped to learning interactions (Doubé 2004).

3. THE FIRST MAIN EXPERIMENT – TRADITIONAL INSTRUCTION

A set of five multimedia learning applications for off-campus introductory computing students was produced by an interdisciplinary team, including experienced instructional designers, professional graphic artists and actors. Each of the five modules received consistently favourable reports from the students who used them (Doubé 2004). The applications specifically dealing with computer programming were subsequently evaluated for their ability to promote learning as well as motivation to learn. An empirical research methodology investigated the multimedia forms described as tutorial and simulation by Laurillard (1992).

3.1 Materials

Two introductory computer programming topics, nested loops and linked lists, are presented as discrete multimedia modules primarily containing visual media of graphics and animations, supported by some optional audio voice-overs.
The modules follow instructional design frameworks based on stages of learning (Gagné 1985), while drawing from other constructivist and instructivist theories including novice-expert theory and principles of androgogy (Knowles 1980). The instructional model guides the learner through stages of skill acquisition. Knowledge is added in small increments to increasingly well-organised structures in long-term memory. Concrete graphical examples illustrate the abstract computer programming topics. Learners navigate sequentially from one screen to the next and can control the pace of their progression. They can navigate forwards and backwards, one screen at a time, or move directly to bookmarked screens. Figure 1 shows a sample screen aiming to prime existing knowledge structures of arrays before embarking on the new topic of linked lists. The sea creature metaphor is expanded throughout the module.

**Approach 1 - An array**

Let’s try an array data structure for our problem of maintaining an alphabetically ordered set.

Insert the word **JellyFish**, in alphabetical order, into the array **SeaCreatures** below. To free the space needed to insert **JellyFish**, you will need to drag any words with a greater alphabetical value one element across the array.

![Array Example](image)

Figure 1. A screen from the first set of multimedia materials: the navigation bar beneath is not shown

### 3.2 The experiments

A pilot study was conducted during a two-hour laboratory session on the topic of linked lists in the second course in a sequence of introductory programming courses. The experimental group received an entire multimedia presentation module. The control group received standard face-to-face instruction. Instruments were a pre-test of learning, a post-test of learning and a self-report of learning and motivation at the end of the class.

Participants appeared to be immersed in the multimedia materials but easily distracted in the face-to-face session. Comments about the multimedia modules were more positive than comments about the face-to-face instruction. The mean score for the pretest was 60% for the entire cohort. In spite of the expressed preference for the multimedia materials, face-to-face instruction appeared to be more effective for learning. Analysis of covariance adjusted the posttest scores relative to the corresponding pretest scores producing a mean adjusted posttest score of 31% for the experimental group and 54% for the control group. Although the control group performed substantially better than the experimental group, the standard deviations were too high for a significant result (F (2,14) = 2.60, P = 0.135).

The pilot study was followed by the first main experiment, conducted during a two-hour laboratory session on the introductory computer programming topic of nested loops. The experimental group once again received materials of an entire multimedia presentation module. Instead of face-to-face instruction, the control group received printed materials equivalent to the multimedia module’s content and supplemented by executable code. A third group received both sets of materials for the purpose of obtaining data for the motivation component of the experiment. All groups were set the same programming task and received pretests and posttests of knowledge, as well as pretests and posttests of motivation.
Initially, participants in the control group frequently compared the printed page of explanation with the corresponding supplied code on the screen, before moving on to the laboratory coding task, after which they rarely referred to the printed page. In contrast, the experimental group spent much longer with the multimedia materials. Once embarked on the programming task, experimental group participants regularly referred back to screens in the multimedia materials, especially those containing code examples.

Analysis of covariance confirmed that the multimedia materials were significantly more motivating than the standard materials ($F(3,17) = 3.62$, $p = 0.05$). The standard laboratory materials proved better for learning than the multimedia materials ($F(2,16) = 2.75$, $p=0.059$) in a weak effect. This experiment was repeated the following year and replicated the results: the control group demonstrated more learning than the multimedia group in a weak effect ($F(2, 36) = 3.68$, $p = 0.06$).

### 3.5 Common findings

One of the most striking effects of the first main experiment was that, according to the posttest results, neither group appeared to have learned very much. When participants with high prior knowledge were omitted from results for the first run of the first main experiment, the mean pretest score was 36.43% and the mean posttest score, adjusted for the pretest score, was 43.28% with the control group improving by over 80% but the multimedia group losing nearly 20% of its pretest mean. In the second run of the experiment, the mean pretest score was 37.56% and the mean posttest score, adjusted for the pretest score, was 24.68%. The control group scored 25% lower on the posttest than on the pretest. The multimedia group scored 34% lower on the posttest than the pretest. This is a very poor result for both the standard laboratory materials and the multimedia materials.

In summary, the first main experiment was conducted twice, and the results of the second run replicated those of the first run. Multimedia materials proved more motivating and less able to promote learning than standard laboratory materials for introductory computer programming. Neither standard nor multimedia materials appeared to consistently promote learning.

### 3.6 Theoretical explanations for the experimental learning outcomes

Explanations for the poorer learning outcomes from the multimedia materials compared with familiar programming laboratory materials are varied and complex. This paper will concentrate on one main subset of relevant theory – split attention (Chandler & Sweller 1992). According to cognitive load theory, extraneous load can be imposed when learners divide their attention between more than one source of information like a graphic on one page and supporting text on another page. One source of information (the graphic) is rapidly deteriorating in working memory while other cognitive resources are being expended, searching for, and matching up, equivalent features in the second source (the text). One means of reducing split attention is to integrate the two sources, thus reducing the search. Multimedia learning theory extends the concept along spatial and temporal dimensions (Mayer 2001). Temporally contiguous sources of information are synchronous, or nearly synchronous, for example, a spoken narrative accompanying a slide presentation. Spatially contiguous sources of information are spatially adjacent to each other, for example textual labels integrated within a graphic, as opposed to a textual description displayed lower down the page or screen.

The control group in the main experiment was able to view code on the screen simultaneously with the equivalent code and its exposition on the printed page. Although the screen and the page were not optimally spatially contiguous, they could be viewed next to each other and were temporally contiguous. Furthermore, the page provided a temporally and partially spatially contiguous reference for the code on the screen during the laboratory coding task. In comparison, the screens of the multimedia materials were neither spatially nor temporally contiguous with each other or with the laboratory programming task. Users had to navigate forwards and backwards between connected sections of the exposition, or toggle to the programming task.

Furthermore, the familiar control materials may have imposed a lighter extraneous cognitive load because participants did not have to learn how to use them. Some individual screens in the multimedia materials contain multiple visual media which may be in competition for cognitive resources, adding to the extraneous cognitive load. In some cases, graphical and textual information are not clearly integrated. Not all illustrative graphics and animations are obviously related to the learning task, and are in breach of the multimedia
learning theory coherence principle (Mayer 2001), creating extraneous cognitive load. In contrast, the control materials were in a single medium – text – with no superfluous components and requiring no integration.

4. THE SECOND MAIN EXPERIMENT – MULTIMEDIA INSTRUCTION

The second main experiment was designed with the primary aim of distinguishing between different types of GUI interactions, while taking into consideration the lessons learned from the first main experiment, including the need to reduce split attention. Some features of the first set of multimedia materials may have simultaneously increased motivation and reduced learning, for example graphical “bells and whistles”. The materials designed for the second main experiment attempted to maximize both learning, and motivation to learn, in the light of these opposing requirements.

Using an empirical research methodology, the fine grain of multimedia forms – individual interactions – were investigated for their impact on both motivation and learning of introductory computer programming. Different types of multimedia graphical user interface interactions were selected according to their ability to be mapped to learning interactions in the format of presentation/response/feedback (Reeves 1998).

4.1 Materials

Produced by a single instructor, the second set of multimedia materials (Figure 2) addresses the topic of two-dimensional arrays, which can be related to the first experimental topic of nested loops. To reduce split attention, explanation is kept to a minimum and the entire presentation occupies a single screen. Each screen

![Feedback](image_url)

Figure 2. Feedback to an incorrect response in the second set of materials
contains a single learning interaction implemented in one of five different graphical user interface interactions, for example, drag and drop, type into a box. The interaction can be repeated on a set of randomized questions until the user chooses to stop.

With the exception of the interaction type, all materials are identical. The top left of the screen contains expository text and code examples. The top right of the screen contains a graphic of a concrete real-world example of the theory – a grid of mailboxes. The expository text is adjacent to, but not integrated into, the graphic, because the feedback for the learning interaction is integrated into the graphic. The bottom left of the screen contains directions for performing the GUI interaction and in some cases the interaction source or target or both. After the user initiates the interaction by pressing the Collect Next Letter button, the mailbox numbers disappear and the bottom right of the screen displays the GUI interaction source, a graphic of a letter with an address corresponding to one of the mailboxes. The task is to select the correct array address. The experimental materials can present immediate feedback and integrate that feedback into the expository graphic: after a correct response, a posted letter is displayed in the selected mailbox; after an incorrect response the hidden mailbox numbers reappear and a textual hint is displayed as shown in Figure 2.

In accord with the experimental objectives, the control materials differ from the experimental materials only in terms of the learning interaction: in a printed version of the multimedia materials, printed questions substitute the multimedia interaction. The answers to the questions are placed in small, faded font, upside down, in the page footer. Only seven questions can fit onto a single page, whereas the randomly generated questions in the experimental materials are unlimited. Cheating is impossible with the experimental materials, whereas the answers on the printed page footer can be checked before the task is completed.

4.2 Findings

In this experiment the mean overall pretest score was 34.70% and the mean adjusted overall posttest score was 57.72%. When questions assessing transfer of learning to unknown situations were omitted, 83.5% of participants scored 50% or more, with a mean score of 76%. Clearly, the materials produced for the second experiment were far more successful at promoting learning than the traditional and multimedia materials in the first set of experiments. The gains in learning were 74% for the print materials and 64% for the combined multimedia interaction groups. When participants with high prior knowledge were omitted, the print group demonstrated the least learning, approaching a significantly lower score than the highest scoring multimedia interaction group, which demonstrated an 125% gain in learning (F (7,95) = 1.91, p=0.10). Variations in motivation by interaction type, student ability and initial motivation are beyond the scope of this paper.

5. DISCUSSION

The first set of materials followed an instructional design strategy soundly based in several well-established instructional design theories, predominantly Gagné’s (1985) stages of learning. The second set of materials was designed in accordance with guidelines from multimedia learning theory (Mayer 2001), aimed at reducing split attention and the resulting extraneous cognitive load (Chandler & Sweller 1992). The second set of materials also aimed to benefit from the increased opportunity for interactivity afforded by multimedia.

The most noticeably different manifestation of the two instructional design approaches was the number of screens occupied by the two sets of materials. The first set of materials leads learners through multiple screens in order to guide them, step-by-step, through stages of learning until they can transfer their knowledge to unfamiliar situations. Some screens provide an opportunity to practice a single task appropriate to the particular stage reached. Although presenting content of an equivalent level of difficulty, the second set of materials presented only the minimum of information on a single screen, and provided unlimited opportunity to practice a task from the final pre-transfer stage of learning.

Multimedia forms are commonly categorized as interactive when they afford user control of pacing and navigation. User control of navigation and pacing is amongst the criteria for good multimedia design in most prominent taxonomies of multimedia learning environments (Sims 1996, Small 1997). But interactions solely for the purpose of navigation and pacing, and not specifically dealing with learning content, pose difficulties for mapping to the presentation/response/feedback components of the experimental definition of a learning interaction. Mapping can be accomplished only with a compromise: presentation is the current screen or
window; response is the user action triggering a progression to the next screen or window; feedback is the presence of the next screen or window. Even so this is unsatisfactory because the mapping is from learning interactivity to the learning environment and not to learning content. In other words, extraneous cognitive load is being mapped to learning content, a contradiction in terms.

5.1 Split attention in the absence of spatial and temporal contiguity

The first set of materials aims to gradually build declarative knowledge frameworks in long-term memory, elaborating them with procedural knowledge at appropriate steps along the way. Although this strategy may work in the classroom or with text-based materials, the constraints of screen-based materials appear to work against it. The screen can effectively convey far less textual information than a printed page can convey, so a page of information will be spread between multiple screens, with a resultant loss of spatial contiguity. Unlike a screen, a printed page is accompanied by the spatial cue of position in a book. Page numbers, headings, tables of contents and indices provide further frames of reference. These cues all help when pieces of information in working memory are being matched to information on recently encountered pages or with knowledge in long-term memory. Navigation from one screen to the next is therefore accompanied by less information about the structure of the content than navigation from one page to the next and may result in less clearly defined structures in long-term memory.

Of vital importance is the time required to proceed from one screen to the next. When understanding of information on the current screen relies on understanding of information on the previous screen, by the time the previous screen can be viewed, the related information may be lost from working memory, especially in a graphically rich presentations.

5.2 The benefits of learning interactivity

Split attention is the main theoretical construct of this discussion (Chandler & Sweller 1992). Two sets of theories relating to multimedia interactivity are the secondary focus – learning as instructor-student dialogue (Laurillard 1993), which can be decomposed into single learning interactions, each in the format of presentation/response/feedback (Reeves 1998). The second set of multimedia materials provided increased opportunity for practice at a fairly advanced level via GUI interactions corresponding to learning interactions.

Participants exposed to both sets of multimedia materials could control the amount of time they spent on a single interaction, the pace between each engagement with the interaction and the number of times they engaged with it, but in the first set of materials, each interaction offered only one result whereas in the second set of materials randomly generated data made repetition worthwhile. Participants in the print group in the second experiment also had fewer opportunities for practice than participants in the equivalent multimedia interactions groups. In the absence of extraneous cognitive load, novice participants in the multimedia interaction groups appeared to benefit from being able to elaborate long-term memory structures with procedural knowledge developed during practice with learning interactions. Students with high prior knowledge may have already had well-defined long-term memory structures in place and appeared to benefit most from the speed and familiarity of print.

5.3 Navigation interactivity and split attention

The other main difference between the two sets of multimedia materials was that the first set contained multiple navigation interactions whereas the second set of materials had none. The link between interactivity and split attention, the two main threads in this discussion, now becomes apparent. Content-related multimedia interactions in the format of learning interactions can contribute to learning by elaborating long-term memory structures with procedural knowledge. In contrast, navigation interactions cannot be clearly mapped to learning interactions and may well impede learning when navigation disrupts spatial or temporal contiguity. In other words, hypermedia may well be counter-productive in many learning situations, especially when one screen builds on information established on a previous screen. Permanently visible structures like hierarchical menus might partially counteract this effect by providing cues with which learners can apprehend the structure of the information and reduce resources involved in searching and matching. Unstructured, in-text hypermedia may well exacerbate the problem.
6. CONCLUSION

The experiments documented in this paper infer that some, but not all, forms of multimedia instruction can promote learning. They provide support for theories suggesting that learners benefit from learning situations simulating learner-instructor dialogue, when components of that dialogue are content-related learning interactions in presentation/response/feedback format. In particular, learning interactivity is a major advantage of multimedia learning materials for domains requiring procedural knowledge, like introductory computer programming. In contrast, unlike content-related interactions, navigation interactions may not support learning if they contribute to split attention, causing extraneous cognitive load. Detailed expositions of content may well impede learning if spread over multiple screens. Designers of multimedia learning applications, including web-based courses, are well-advised to keep expository content to a minimum and to concentrate on providing opportunities for practice.

ACKNOWLEDGEMENTS

Thank you to Dianne Hagan and Judy Sheard of CERG at Monash University for their assistance.

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