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DEVELOPMENT ARTICLE

Visualizing mental models: understanding cognitive change to support teaching and learning of multimedia design and development

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Abstract The use of advanced instructional design (ID) principles, especially those that include a collaborative authoring environment is becoming ever more critical in the successful workplace. Faculty in instructional technology programs who provide an environment that effectively nourishes these ID skills have a responsibility to continually evaluate and update their instructional methods to ensure that course goals are met. Using students' drawings of their expressed mental models as an assessment tool is one approach that helps evaluate teaching methods, determine what students have learned, and how they have conceptualized important concepts. In this study, teams of instructional technology graduate students in a two-semester, multimedia design and development course used an authoring program to create multimedia projects for real clients. This study examined the cognitive changes that occurred when these students were immersed in a technology-rich, collaborative environment. Comparison of students' visual representations of their mental models of multimedia design and development from the beginning and end of the course provided insight into conceptual changes that occurred in regards to the multimedia course, its goals, and the collaborative process. Analysis of students' drawings of their mental models indicated substantial transformations from linear, individualistic, and skills-based thinking to recursive, collaborative, and team-oriented concepts. This data provides evidence that the visual, graphic nature of mental models provides a coherent, fluid, and detailed representation of students' thinking, one that captures a level of richness that may be missing from essay methods, product assessment, or class evaluations.

Keywords Visualization · Drawings · Mental models · Assessment of cognitive models · Semiotic analysis · Multimedia design and development

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Introduction

The workplaces of the 21st century are constantly changing and require skills that are not merely exemplified as technological—logical, analytical, and technical, but also those represented as value skills—creativity, critical thinking, the capability to see the big picture, and the ability to work effectively in a team (Bevins et al. 2012; Partnership for 21st Century Skills 2010; Rosenstock and Riordan 2013). It is the responsibility of education systems "to prepare students for the challenges and opportunities of the 21st Century" (Carter 2011, p. 14). To serve this need, many graduate programs in instructional technology require advanced training in project-based multimedia design that emphasize the development of these skills (e.g., the University of Georgia's Learning, Design and Technology graduate program in Instructional Design and Development). However, teaching multimedia design and development in isolated courses may decontextualize the learning experience for students. In addition, Clinton and Rieber (2010) noted that the typical one-course/one instructor model may place "limitations on the authenticity of the experience" (p. 755), and students may not be prepared to respond to problems that arise in "ill-structured consultant–client relationships" (p. 756). Situating the learning experience in a team-based, project approach may allow students to develop strong technical skills and, at the same time, build value skills such as collaboration and communication that are needed for careers in instructional technology related jobs (Ritzhaupt and Martin 2014; van Rooij 2010). As Neo (2007) stated, "Learning takes place in a meaningful, authentic context and is a social, collaborative activity, where peers play an important role in encouraging learning" (p. 152).

Assessing students' achievement of course objectives is critical, especially in a situated, collaborative environment. Instructors can measure students' achievement of some course objectives through assessing the project developed (Clinton and Rieber 2010); often a rubric with categories such as content, audience consideration, and design qualities is used to evaluate multimedia products (Cox et al. 2010; Green and Brown 2002; Hung et al. 2013; Williams 2011). Other course objectives can be measured through discussion, through observations of behavior, through reflective journaling, and through tests or quizzes of factual knowledge (Clinton and Rieber 2010). However, the changes in ideas and perceptions about the collaborative design and development process are more difficult to observe and measure.

I have taught graduate courses on collaborative design and development of multimedia for many years, and I have received numerous anecdotal comments from students about how working in a team to design an actual multimedia project was a life-changing event. Many students have written me to reflect on the positive aspects of the experience. Here is an example of a student reflection long after the course was over:

> We functioned as a team and not a collection of individuals. Our group rose to the highest definition of a team. While we can only speak from our team's experience, we think that this class activity has provided a unique and positive opportunity to experience and receive the benefits of working with others. As a group, we were able to create something that was beyond the ability of any one of us to accomplish individually. (Anonymous student email 2007).

I became curious about what changes occurred in the students in terms of their mental models during the course experience. I am able to evaluate the team's instructional design skills by examining their team's project notebook that contains a comprehensive report including the needs analysis, stated goals, instructional strategies, and their assessment instruments. I can measure their technology skills by examining the final product and reading the report on who contributed what to the project. I can check their evaluation skills by observing the pilot test and reading their evaluation report. But I wanted to "see" inside their brains to observe whether their perceptions about the entire process changed as a result of the team experience itself.

As a result, I focused on trying to understand the cognitive changes that occurred as part of the course experience by analyzing students' drawings, visual representations of their externalized mental models of multimedia design and development, completed at the beginning and end of the course. Using these drawings as assessment tools is one approach that could help instructors evaluate their teaching methods as well as determine what students have learned and how they conceptualized, and perhaps internalized, important concepts that are not easily measured through standardized assessment. Researchers have suggested that by understanding and diagnosing an individual's cognitive structure, educators can design more effective instruction (Ifenthaler 2011) and "relate new materials to existing slots or anchors within the learners' cognitive structures" (Ifenthaler et al. 2009, p. 41). According to Stout et al. (1997), measures of knowledge structures may be more likely to uncover effects of learning, as they are less susceptible to attenuation and are sensitive enough to capture differences even when all participants have some familiarity with the concepts. A report by the National Research Council Committee on Science Learning, *Taking Science to School*, recommended, "To support student sense-making, teachers need to know how students think, have strategies for eliciting their thinking as it develops, and use their own knowledge flexibly in order to interpret and respond strategically to student thinking" (p. 312).

In this study, students were engaged in a two-semester graduate course that immersed them in a project-based learning environment while they were designing multimedia projects for actual clients. The main objectives of the course were to enable students to use a collaborative design process while learning the authoring software, and then apply this knowledge in an authentic team-based environment. The course focused on a practitioner model of instructional design (Seels and Glasgow 1998), the application and use of specific authoring software, and the development of workplace and teamwork skills.

Objectives of the study

This study was guided by two questions: (1) What mental models do beginning designers and developers of multimedia possess? (2) How do these mental models change after an exposure to a project-based, authentic learning environment in which the authoring software was used as a cognitive tool? The goal of this study was to seek patterns in students' visualizations of their externalized mental models of multimedia design and development in order to determine whether the students acquired the knowledge and skills related to the course objectives.

Mental models

Scottish psychologist, Kenneth Craik, is credited with first coining the term "mental model" in 1943. Craik's definition of mental model was that of a thought process that provides a representation of some entity or system. Craik's reasoning was based on the ability of humans to explore real and imaginary situations mentally, and he proposed the idea of thinking models that parallel reality. Researchers have suggested that a person develops mental models to represent knowledge used in cognitive tasks and to make sense of experiences in the physical world (Coll and Treagust 2003; Nersessian 2008).

There are some important considerations associated with mental models that are directly related to this research study. The term, mental models, is used specifically in this study rather than the more general term, knowledge structures, because of the defining elements of these concepts. First, a mental model is different from declarative knowledge in that it represents a holistic, schematic organization of knowledge (i.e., structural knowledge) in which a set of ideas is related together in a meaningful way, rather than the amount of acquired knowledge (Johnson-Laird 1983; Johnson-Laird et al. 1998; Merrill and Gilbert 2008). Similar to pictures in Wittgenstein's (1922) "picture" theory of the meaning of language, mental models are simpler and less complicated than real-world phenomena. Both real-world phenomena and mental models are similar in structure (e.g., an architect's scale model of a building or a biologist's model of DNA), and this similarity allows the holder of the model, whether expert or novice, to make mental inferences about the phenomenon that may also be true in the real world.

Second, mental models are highly individualized and constantly changing as more input and learning take place (Lambert and Walker 1995). The structural knowledge and organization of a mental model changes when learners construct new knowledge and modify existing knowledge as they experience situations, problems, circumstances, and other events in learning settings (Tzeng and Schwen 2003). A mental model can also become a system with which exploratory inputs can be fed and observed for its resultant behavior (Carroll and Olson 1988). Although mental models are different for novices and experts, the models of both continue to change as a person gains more knowledge.

Third, mental models are frequently unscientific and may contain inaccurate information. Norman (1983) noted, "…people's mental models are frequently deficient in a number of ways perhaps including contradictory, erroneous, and unnecessary concepts" (p. 14). In *The Psychology of Everyday Things* (1988), Norman pointed out, "Mental models are often constructed from fragmentary evidence, with but a poor understanding of what is happening, and with a kind of naïve psychology that postulates causes, mechanism, and relationships even where there are none" (p. 38).

Despite these limitations, mental models play a very important role in understanding changes in human learning. One way to measure the change in cognitive structures is to examine learners' externalized mental models since they can reflect the type and level of construction that has occurred.

Examining mental models

Visual techniques of knowledge representation

Gilbert and Boulter (2000) noted that actual mental models are inaccessible to the researcher, who must therefore rely on "expressed models" to infer them. Although there is not a universally accepted technique, researchers have proposed broad categories for analyzing externalized mental models. For example, Jonassen and Cho (2008) listed five ways to measure mental models: (1) problem solving performance, (2) verbal reports such as structured interviews and think-aloud protocols, (3) drawings, (4) categorization of instances that identify cognitive differences between novices and experts, and (5) conceptual pattern representations such a concept maps. Al-Diban and Ifenthaler (2011) condensed these techniques into two primary methods: graphical (e.g., the mind tools technique of Jonassen and Cho 2008) and language-based approaches (e.g., computer linguistic techniques of Seel et al. 2009). Graphical approaches may use representations that are created with computer software or use predetermined components as building blocks (Ahlberg 2008; Buzan 1974; Mioduser and Dagan 2007; Novak and Musonda 1991). The language-based approaches may originate from audio such as an interview (Brock et al. 2008) or a listing of concepts (Zhang 2010) that are subsequently transformed into a graphical representations using computer software such as Pathfinder (Schvaneveldt 1990) that generates a graphical representation of the relatedness of concepts.

These tools provide ways to assess students' expressed mental models of complex concepts and are useful for obtaining information on how the learner organizes information, what key concepts are included, and what types of relationships exist between the concepts. However, these methods use predetermined structures and a set of rules for creating these visual representations. Expressing mental models through a drawing process rather than a preset format may provide individuals with a higher degree of freedom to express concepts in ways that they may have otherwise been unable to do (Baghban 2007). Jonassen and Cho (2008) noted that, "Drawings can provide information about pictorial specs of mental models, which are difficult to be measured by verbal reports" (p. 148).

Assessing learning through drawings

Researchers have used visual representations drawn by students to uncover hidden factors related to learning. For example, Van der Veen (2012) posited, "Drawing is a means by which a learner (artist) can get in touch with and express his or her own inner language, and is thus a way to connect students' internal translations of external experiences through symbolic representations" (p. 365). Vosniadou and Brewer (1992) investigated the development of young children's conceptual knowledge of the earth's shape by analyzing drawings made during an individual interview with the child using the question, "Can you draw a picture of the earth?" Additional prompts such as "Show me the moon and stars" and "Show me where people live" provided additional stimuli for the child to add features to the drawings that the Vosniadou and Brewer (1992) subsequently used to elicit further information about the child's mental model of the earth. MacPhail and Kinchin (2004) investigated students' perceptions of a sports education program through the use of student drawings at the end of the experience. They used the data from the drawings to complement findings from interviews in a larger study. Chapman et al. (2010) used drawings by elementary school students to understand how these students perceive reading instruction within their language arts classrooms. The researchers stated that the drawings "… represent the constructivist context of the classroom during reading instruction and captures the interaction during a mediated instructional moment" (Chapman et al. 2010, p. 125).

Katz et al. (2011) used drawings made by teacher candidates before and after participating in an informal afterschool science internship to assess their professional identity development. Researchers identified themes that emerged from the data and stated that, "The mental models provided a lens through which we could explore how the teachers' were identifying as reform-oriented teachers of science" (Katz et al. 2011, p. 1180). Cainey et al. (2012) assessed informal learning by using pre-trip and post-trip drawings by young children after visiting an aquarium. They proposed that the comparison of the drawings showed that significant informal learning had occurred because of the children's participation in a guided visit.

Van der Veen (2012) analyzed student drawings and written commentaries to examine students' preferred learning modalities, understanding of physics concepts, and preexisting attitudes towards science. Van der Veen suggested that by understanding students' knowledge and attitudes about a topic, teachers could design appropriate and effective instruction. In addition, van der Veen reported benefits for the students as well,

> …drawing should be seen as a useful exercise for students as a means of organizing their thinking about difficult concepts as well as a potential learning strategy for effecting change… the process of expressing difficult concepts through artistic visualization can be a potentially transformative experience for the learner. (p. 398)

Other studies suggest that the act of drawing visual representations may improve student outcomes. Edens and Potter (2007) examined the use of schematic drawings for mathematical problem solving by 4th and 5th grade students. Edens and Potter (2007) found that the use of schematic drawings was significantly related to problem-solving performance, and they asserted that a teacher could use these drawings to assess the students' level of spatial understanding. In a subsequent study, Edens and Potter (2008) proposed that the more "schematic-like" visual representations, as opposed to the more pictorial, were more indicative of higher problem solving performance. The gain in problem solving performance was not only for the problem for which the representation was created, but the gain also correlated with students' abilities to solve successive problems.

The project-based learning experience

Authentic project-based learning environments have the potential to provide an environment that allows students to experience learning in situated contexts, and these experiences can enrich and change their mental models. In project-based learning, instruction and learning occur within the context of a challenging project (Lee and Lim 2012; Thomas 2000; Vega and Brown 2013). Using a project that both mirrors complicated tasks encountered in today's workplaces and has real-world clients can act as a focus and catalyst for learning. A project-based learning approach is learner-centered and encompasses multiple learning communities—peers, clients, users, instructors, and experts.

This study was situated in a two-semester, graduate course in which I was the instructor. The course focused on advanced instructional design principles, the application and use of an authoring program to create a multimedia project for an actual client, and the development of workplace and team skills needed for optimal interaction and collaboration. Participants in this course were 13 graduate (master's and doctoral level) instructional technology students who had completed introductory courses in instructional design and courseware authoring. Ten were female and three were male; all were educators or had held education-related jobs.

On the first night of class, 11 students completed a brief questionnaire of self-reported instructional design skills, multimedia skills, and team experiences, the three main topics of the course. Two students did not complete the questionnaire because of late enrollment. Students reported their competence using a scale of 1 (low) to 5 (high). The purpose of the questionnaire was to help me put the students into groups of equal skill sets. Table 1 shows the mean and standard deviation for the responses ($N = 11$) to each of the items.

I presented brief descriptions of the proposed projects and asked students to rank their first, second, and third choices on a ballot. The second week of class, I assigned students to three different teams based on a combination of factors: (1) the results of the self-reported instructional design skills, multimedia skills, and team experiences, (2) my knowledge of each student's abilities and background, and (3) student preference. Most students received either their first or second choice. Clients for the projects included the Children's Museum of Houston and the Museum of Fine Arts, Houston.

Table 1 Self-reported instructional design skills, technology skills, and team experience of students at the beginning of the course

	M	*SD*
Using flowcharts	3.09	1.14
Organizing content	3.09	0.94
Taking photographs	3.00	1.10
Using storyboards	2.91	1.14
Designing instructional framework	2.45	1.21
Creating graphics	2.45	1.37
Creating navigation maps	2.27	1.35
Programming/authoring	2.27	1.35
Multimedia project experience	2.18	1.17
Designing navigation structures	2.18	1.08
Building prototype	2.09	1.58
Designing interface	2.00	1.18
Creating animation	1.91	0.54
Producing video	1.91	0.94
Producing audio	1.64	0.81
Digitizing audio	1.64	0.81
Testing program	1.60	0.84
Costing project	1.45	0.82
Digitizing video	1.45	0.69

M is shown in descending order

During the first part of the course (mid-August through mid-December), the teams identified instructional needs, formulated objectives, wrote content, and created storyboards for the project. In the second part of the course (mid-January through mid-May), the teams designed the interface and graphical elements, developed the project, and evaluated the software with target users. Throughout the design and development of the project, the teams worked closely with their clients in an iterative and recursive process that provided a meaningful situated context for their learning experience. Over the nine-month experience, my role as instructor changed from information provider to facilitator to observer as teams assumed increasing responsibility for both their learning process and their product. The structure that was imposed on students also diminished progressively over the 9 month time period until the students, working in their teams, had complete control over the organization of the class as well as the discussion.

Methods and data sources

During the first class meeting, students created a visual representation of their concept of multimedia design and development on a single blank piece of paper using pencils, pens, or color markers. I used these instructions to avoid students being influenced by computerized, pre-determined formats (e.g., applications such as Inspiration^{TM}). At the end of the course, I again asked students to represent their externalized mental models of multimedia design and development using the same parameters as the first. Students did not see or discuss their pre- or post-course mental model representations after creating them.

I also used other techniques to gather data about the extended multimedia design and development experience. Each team member completed peer evaluations for his/her team members and himself/herself at the middle (December) and end (May) of the courses.

These evaluations used a Likert scale and open ended responses to questions about team performance, member roles, and achievement of course objectives. In addition, I collected both individual and team reports that students posted as documentation of weekly progress using an online form.

Although I used all of these forms of data as feedback on the course experience as well as in my assessment of both individual students and the teams, I used the students' pre- and post-course drawings to specifically look for significant themes that documented any changes in their expressed mental models of multimedia design and development. The process included looking for themes and patterns as well as examining the structure and organization of their visual representations (Gentner and Stevens 1983; Johnson-Laird 1983).

Organizing and measuring mental models

Doyle et al. (2008) noted that there are a variety of formal techniques used by researchers to organize and represent mental model information. These include systems flow diagrams, causal loop diagrams, influence diagrams, hexagons, and social fabric matrices. I felt that the problem with using one of these techniques was that these techniques were designed to facilitate change in mental models, not to measure change. Doyle et al. (2008) stated "…the very features that make them valuable for changing mental models …simultaneously make them unsuitable for measuring that change in an accurate and unbiased way" (p. 270).

Semiotic analysis

For this study, I decided to use semiotic analysis of the pre- and post-course visual representations of their mental models that the students completed. Semiotics is a philosophical approach that seeks to interpret messages in terms of their signs and patterns of symbolism (Moriarty, 1995). As a field of study, semiotics offers a framework for understanding visual representations of concepts and provides a way to understand and compare different representations. Rose (2012) proposed that semiotics, "… offers a very full box of analytical tools for taking an image apart and tracing how it works in relation to broader systems of meaning" (p. 105). As a mode of analysis, semiotics attempts to uncover the rules and principles that account for patterns of behavior as well as to interpret communication patterns through the use of metaphors. Eco (1990) stated, "A metaphor substitutes one expression for another in order to produce an expansion (or a 'condensation') of knowledge at the semantic level" (p. 139).

Kress and van Leeuwen (1996) proposed a vocabulary for visual semiotics that provides a descriptive framework for the analysis in this research study: (1) representational meaning, how the image and its parts represent the world; (2) interactive meaning, the interaction that the image contains or represents; and (3) compositional meaning, how the layout, placement and salience of the image combine to provide the total composition. Representational meaning is further classified into one of two visual syntactic patterns: narrative structures that contain vectors that either directly or subconsciously connect parts and direct the gaze of the viewer, and conceptual structures that visually define, analyze or classify parts (Jewitt and Oyama 2001). Interactive meaning is divided into three parts: (1) contact, making contact with the viewer to establish a relationship; (2) distance, the framing of an image to be close or far; and (3) point of view, the perspective from which the image is taken. Compositional meaning is divided into four parts: (1) information value, where the elements are placed in a composition; 2) framing, how the elements in a composition are 'connected' or 'disconnected' from one another; (3) salience, making some elements stand out more than others; and (4) modality, the form of the visual itself. For this study, I used only representational meaning and compositional meaning to structure the analysis since the visuals were drawings, and interactive meaning was difficult to determine.

Changes in mental models

This study primarily focused on the pre- and post- visualizations of the mental models of twelve students who consented to be part of the study. Overall, the participants in this study demonstrated significant changes in their mental models over the 2-semester period. Three major themes emerged from the comparison of pre- and post-course representations of their mental models. The themes indicated change from a linear, individualistic, and skills-based model to a recursive, collaborative, and team-oriented model. The themes were:

1. *Structure and organization* of the mental models changed from isolated and individualistic representations to collaborative and team oriented processes.
2. *The mindset and attitudes* of the students changed from skills in isolation to teamwork and collaboration.
3. *Knowledge constructs* in the representations changed from a focus on small, isolated units or the individual parts to a focus on the whole, a cognitive model that included the big picture.

In order to develop these themes, I worked with another faculty member who had expertise in both instructional technology and qualitative research to look for patterns in the students' representations. We viewed the pre- and post-course drawings side-by-side and discussed what we saw in the representations aloud. We voiced our thoughts about each student's pre- and post-course drawing separately and as a pair for comparison. In this process we sought confirming and disconfirming membership of these patterns under possible categories. We each proposed statements about what we saw in the drawings and continued to discuss each set of drawings until we agreed with the analysis. This cycle of discussion resulted in the development of the final themes summarized in Tables 2, 3 and 4.

It is important to note that the post-course drawings of mental models are very distinct from the pre-course drawings, perhaps as expected. What makes these findings even more interesting is the display of specific emphasis on collaborative teamwork and the importance of both technical and value skills in the final representations.

In addition to using semiotic framework to analyze the mental models, we used four key objectives of the course as lenses through which to further analyze the representations: (1) Multimedia, (2) Authoring Software, (3) Design and Development in Collaborative Teams, and (4) Instructional Design. These key aspects are intrinsic to the multimedia design and development process, and as the instructor and course developer, I had used these objectives to build the course outcomes and structure the students' experiences.

Analysis of the visual representations suggests two distinct ideas. First, the project-based learning experience itself, not merely technical skills or theoretical learning (e.g., instructional design theory) appeared to influence the students' construction of a post-course visualization that reflected the inherent complexity of the process of multimedia design and development. Second, isolated and discrete concepts about multimedia design and development shown in the pre-course visualizations evolved to show richer and more complex understandings of the process.

Table 2 Changes in students' mental models grouped by theme 1, structure and organization

Pre-course drawing	Post-course drawing
Each step of the multimedia design and development process is carefully contained in its own space	Phases of the multimedia design and development process are overlapping, intermingled, and recursive
Process is represented as linear and directional (indicated by one way arrows)	Process is largely represented as overlapping, circular, and spiral (represented by multi-directional, often circular movement)
Process has few, simple steps	Process has multiple interactive processes
Job titles such as designer, developer, client, user, are largely isolated from each other	Job titles are not a strong focus; instead the focus is on the output of that phase
Process is ordered, separated, and regimented	Process is less structured, more dynamic and inter-related

Table 3 Changes in students' mental models grouped by theme 2, mindset and attitudes

Pre-course drawing	Post-course drawing
Individualistic mindset is primary in the representations. (What do I need to know? What can I do?)	Collaborative mindset is central in the representation. (What does the team do?)
If used, the team is only a part of the whole process	The team is an all-encompassing part of the entire process
Little appreciation of the value of the team is demonstrated	The focus on the team is well demonstrated
Few value skills are represented	Many value skills (e.g., creativity, critical thinking, and communication) are represented
Emphasis on hands-on abilities such as using a specific application is noted in the representations	Emphasis on cognitive skills such as theoretical planning and knowledge of process is noted in the representations

Table 4 Changes in students' mental models grouped by theme 3, knowledge constructs

Pre-course drawing	Post-course drawing
Less content is shown in the representation	Dense content is shown in the representation
Focus of the content is on technical skills	Focus of the content is on multiple skills (including both technical and value skills) and how they relate
If used, teamwork is isolated and is a small part	Teamwork is usually at the center and is a large part
Concepts described in the content are simple and lacking continuity	Concepts described in the content are complex and cohesive
Instructional design ideas depicted are largely that of a simple systematic model	Instructional design ideas depicted are more complex and originate from a need, rather than a stepwise model

It is also important to note that some of the post-course drawings became less complex than the pre-course drawings. For example, Student 3's pre-course drawing illustrated sixteen words that were represented in a linear fashion with directional arrows. In the post-course drawing, Student 3 drew a circular design with the "need/topic" represented in the inner circle, surrounded by a circle marked “approach/strategy” and another circle marked “product.” Other smaller circles were connected to the three middle circles with lines and were labeled “visual design,” “client review,” “content (writing),” “testing,” “graphics,” “internal review,” “programming,” and “instructional design.” Although the map is visually less complex, the post-course map shows a much more connected mental model with all of the elements contributing the central concept that is expressed as “need.” I believe that the post-course drawing reflects a richer understanding of the concepts because extraneous words and ideas that were included in the pre-course drawing were omitted, and the concepts shown in the post-course map are broader and more encompassing.

I have selected two students’ pre- and post-course drawings to illustrate my interpretation of the drawings and the changes I have noted. While participants’ pre-course mental models differed, they were all clearly influenced by their prior experiences and knowledge of computer skills, multimedia experiences, and team strategies. In the post-course representations, the participants’ mental models showed an increase in the importance of collaboration, teamwork, and value skills. Full-color images of all of the students’ pre- and post-course representations may be viewed here: http://atlantis.coe.uh.edu/itresearch.

Student 1

The visual representation of Student 1’s pre-course mental model is presented in Fig. 1. Student 1-PRE contains 17 items and has four streams coming off of one main concept at the center of the representation: *technical skills*. The four streams are: *applications*, *choice of application*, *learning curve*, and *implementation. Applications* is divided into four subtopics: *graphics*, *video*, *voice*, and *Authorware. Choice of application* is divided into three subtopics: *Why?*, *Where?*, and *When? Learning curve* is divided into three subtopics: *book resources, tutoring, and time.* The fourth stream, *implementation*, is divided into two subtopics: *objective of the project* and *team work.*

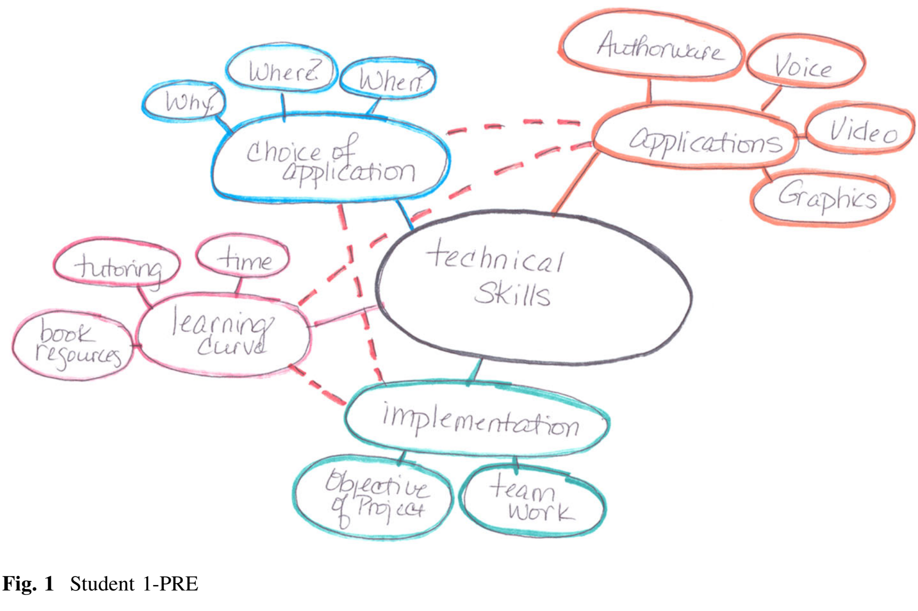

Fig. 1 Student 1-PRE

Semiotic analysis

Representational meaning

The representation of Student 1's PRE mental model is similar to a concept map and contains solid lines that are used to connect the streams to the main topic and dotted lines that are used to indicate connections between subtopics. It is substantially different from a concept map in that it does not contain words that specify the relationship between the two concepts.

Compositional meaning

The placement of elements in the PRE model emphasizes *technical skills* since the oval that contains those words is larger and centered. The elements are all connected with a line, but each element 'stands alone' in a separate oval that doesn't directly touch another. Four dotted lines connect *learning curve* and *implementation*, *learning curve* and *applications, choice of application* and *implementation,* and *choice of application* and *applications*. Color is used to further classify elements into groups, but it doesn't appear to serve any other purpose. The shapes are all organic, but similar. Size of the ovals and placement indicate importance of each element. There is an open space at the lower right side of the model that makes it seem incomplete and lop-sided as if another stream was to be placed there.

Course objectives analysis

Multimedia

Student 1-PRE presents a techno-centric view of multimedia. With technical skills at the center of the representation, there seems to be an emphasis on hands-on abilities rather than cognitive skills such as knowledge of the whole process or an instructional design model. The student does show four aspects of multimedia: the authoring software, video, voice and graphics.

Authoring software

Student 1-PRE has a stream that lists applications for authoring software and includes several different types of media. Instead of listing generic applications for the authoring program, Student 1-PRE lists the specific software used for the projects.

Design and development in collaborative teams

Student 1-PRE lists one item related to design teams: team work. No characteristic or skill associated with working in a team is shown.

Instructional design

Student 1-PRE provides one item related to instructional design: objective of project. Although all students had knowledge of a generic instructional design model through previous coursework, individual steps of an ID model were rarely used in the PRE representations.

Student 1-POST (Fig. 2) contains 38 items and has interlocking circles around one main concept at the center: *Goal: Multimedia Product*. There are not clear streams; instead the circles, with the word *skill* at each juncture of the circles, seem to be connected and interrelated. In comparison to the student's first visual representation, it shows a much richer view of multimedia and the surrounding factors. In addition, the interrelatedness of the items begins to show the complexity of the cognitive model and the relationships of the items. Many skills, rather than merely technical skills, are a part of the complex process.

Semiotic analysis

Representational meaning

This image does not contain vectors; instead, the conceptual structures, circles, are joined and interconnected like a ring with no beginning and end. The meaning is clear that the creator meant for the elements to be seen as interrelated as well as having shared boundaries much like a Venn diagram.

Compositional meaning

The elements are placed significantly in the composition with overlapping edges and mutual boundaries providing a connected, cohesive framing. It is significant that no element stands out more than others with the exception of the center label, *Goal: Multimedia Product*.

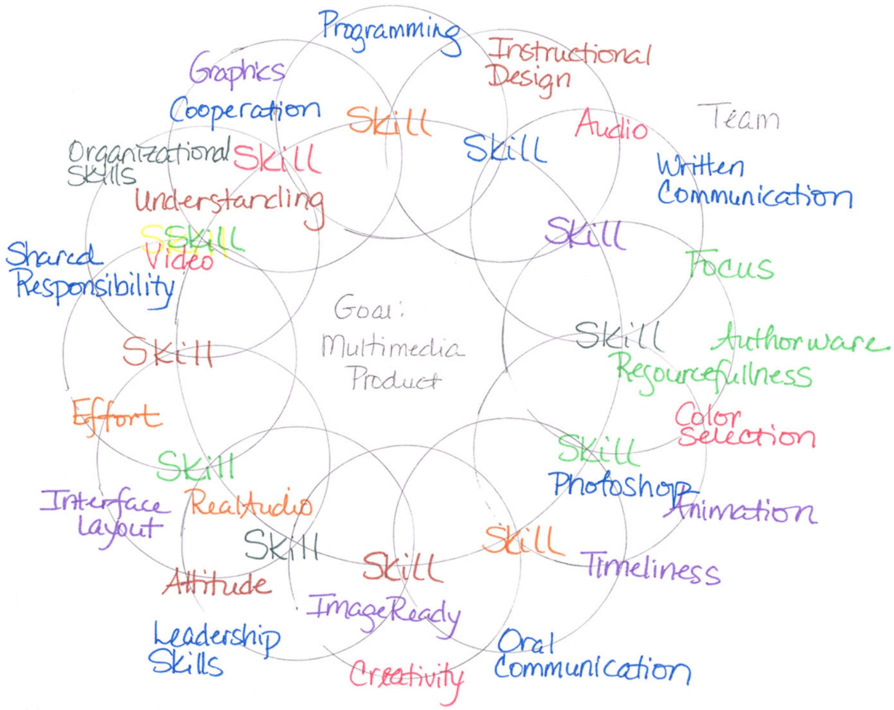

Fig. 2 Student 1-POST

Course objectives analysis

Multimedia

Student 1-POST presents a very different view of multimedia than Student 1-PRE. *Multimedia* is integrated into the center of the representation, and there is less focus on the software application and more emphasis on the collaborative product.

Authoring

Software Student 1-POST integrates authoring skills throughout the representation with such items as *Audio*, *Interface Layout, Graphics, Animation*, and *Authorware*™.

Design and sevelopment in collaborative teams

Student 1-POST contains several items related to team qualities in addition to the one item, *Team,* that was used in the PRE representation. Items related to design teams include: *Cooperation, Shared Responsibility, Written Communication*, and *Oral Communication*, all important aspects of value skills.

Instructional design

Student 1-POST provides one item: *instructional design*. At first glance, this omission seemed negative. However, the omission could be indicative that the student had internalized core tenets of instructional design into the entire process. One of the objectives of the course was that the final product demonstrates the participants' knowledge of a collaborative instructional design model. The absence of specific steps in the instructional design process in the final mental model representation supports the idea that internalization may have occurred. Other evidence we used to make the assertion of internalization was a careful evaluation of the final multimedia product, by the students, instructors and clients, as well as a group of target users. Additional contributing indicators of this internalization included observations of the team's application of the instructional design process as well as individual and team journals.

Student 2

The visual representation of Student 2's pre-course mental model is presented in Fig. 3. Student 2-PRE emphasizes skills—the main topic noted in the center circle. The representation contains 32 items and has five streams coming off of one main concept at the center of the representation: *skills for CUIN 7327* (the name of the course). It is interesting to note that the pre-course representation has words immediately above each subtopic that create more meaning; these words are shown below in brackets.

The five streams are: *technical skills*, *instructional design skills, public relations skills, knowledge acquisition skills,* and *teamwork skills. Technical skills* is divided into six subtopics: [learn] *program, [create method of] navigation, [add] applications, [test &] troubleshoot, [adapt to different] levels,* and *[gain skills in] programming. Instructional design skills* is divided into five subtopics: *[add] graphics, [decide on] sequence, [make it] user-friendly, [appeal to audience], and [create] layout. Public relations skills with client* is divided into four subtopics: *[assess] needs, [produce] presentations, [good]*

Fig. 3 Student 2-PRE

communication, and [present] ideas. The fourth stream, *knowledge acquisition skills* is divided into six subtopics: *[research] topic, [gather] information [from client], [align] content [with objectives], [write] content, [edit] content, and [establish] assessment. Teamwork skills* is divided into six subtopics: *[set aside] time, [equal] participation, [be] flexible, trust, [open] communication,* and *[build upon] strength.*

Semiotic analysis

Representational meaning

The pre-course image does not contain obvious vectors; instead, the conceptual elements, shapes like flower petals, are arranged around the center circle. The placement of the shapes is very structured, and no shape touches another. Each subtopic is carefully, but invisibly, joined to the corresponding topic.

Compositional meaning

The elements share no boundaries. Each of the streams is roughly equal size, and each of the subtopics is approximately the shape and dimensions. No element stands out more than others with the exception of the center circle, *skills for CUIN 7327*. The composition is carefully balanced, unlike Student 1's PRE lopsided representation, and each element is positioned precisely so nothing feels random or haphazard. The modality of the image is decorative and resembles a poster or graphic rather than a representation of a mental model.

Course objectives analysis

Multimedia

Student 2-PRE also emphasizes skills but only one, *[add] graphics* under the stream, *instructional design skills*, recognizes the multimedia aspect of the course. There is no mention of any other feature of multimedia such as audio, video, animation, interactivity, or non-linear navigation.

Authoring software

Student 2-PRE has stream for *technical skills* that contains *[learn] program* and *[gain skills in] programming*, but no mention is made of the particular software program used. The emphasis is on programming, not authoring.

Design and development in collaborative teams

Student 2-PRE created a stream called *teamwork skills*, noting needs of the team to *[set aside] time*, have *[equal] participation*, to *[be] flexible*, to *trust*, to have *[open] communication*, and to *[build upon] strengths.*

Instructional design

Student 2-PRE provides several subtopics related to instructional design, but interestingly enough they are scattered in other streams as well as the one labeled *instructional design skills*. For example, *[establish] assessment* is under knowledge acquisition skills, and *[assess] needs* in under public relations skills with client. The items listed under instructional design skills are a bit unusual as well. Three items, *[add] graphics*, *[create] layout* and *[make it] user friendly* are more graphic design skills rather than instructional design skills.

Overall, Student 2's PRE mental model representation is unusual because each item is carefully segmented and roughly equidistant from each other. The shapes are self-contained and stylized, and they are not connected with a mechanical means like a line. The interconnectedness of the items and their relationship to each other, except for falling under a particular stream, is not demonstrated. As far as size of the elements, each of the five main streams is the same size and the subtopics are the same size; size is not used to emphasize any subtopic.

Student 2-POST (Fig. 4) contains 20 items and is composed of very organic, freeform shapes that seem to fit into one another like puzzle pieces. Like Student 1's POST representation, all of the components seem to be connected and interrelated. Similar to the differences between Student 1's PRE and POST representations, Student 2's POST visual representation shows a much richer and deeper view of multimedia and the surrounding factors. The interrelatedness of the items also shows the complexity of the cognitive model

Fig. 4 Student 2-POST

and the relationships of the items. The largest shape, *Teamwork*, plays a dominant role in the representation.

Semiotic analysis

Representational meaning

While the shapes in Student 2's PRE representation were very crisp and singular, the shapes in the POST representation almost seem to be growing and moving like living organisms. These amorphous figures, while still not physically touching, seem to be invisibly connected to one another because of the way they are drawn in mirror edges—each edge the reverse of the one next to it.

Compositional meaning

Two techniques, color and size, are used deliberately and play an important part in understanding Student 2's POST representation. Color is used to show relationships and hierarchy as well as to indicate categories. Size is used to show importance. The top shape, *Multimedia design skills*, is made up of a combination of colors—green, yellow, red, blue and purple—suggesting that this topic may be the combination of all of the subtopics. *Formative evaluation* on the top left is solid red, and *summative evaluation* on the top right is solid yellow. The next shape, which is also the largest, is *Teamwork* and it directly reflects the four main colors of the shapes directly below it, green, blue, purple, and red, which could indicate that it is composed of these subtopics.

The color in these subtopics is equally descriptive. The first subtopic under *Teamwork* and on the left side is labeled *Time & Effort*. Below it, in shades of green ranging from dark green to light green, are the subtopics of *Determination* and *Dedication*. The next shape, labeled *Graphic skills,* is colored in blue, and below, in shades from dark to light blue, are shapes labeled *Layout, Design, Artwork*, and *Sound*. The shape labeled *Authorware programming skills* is purple, and the shapes below are *Knowledge of icons, Variables & functions*, and *Navigation*. Again, each shape ranges from dark purple for the top icon to light purple for the bottom icon. Finally, a red shape labeled *Organization* is shown on the far right with the shapes below labeled *Timeline, Communication,* and *Focus* in shades of dark to light red.

Course objectives analysis

Multimedia

Student 2-POST presents a very different view of multimedia than Student 2-PRE. *Multimedia design skills* is at the top of the model and is integrated into the center of the representation. The shape resembles a person, and there is emphasis on formative and summative evaluation.

Authoring software

Student 2-POST contains a subtopic called *Authorware programming skills* with other components of *knowledge of icons, variables & functions*, and *navigation*.

Design and development in collaborative teams

Student 2-POST emphasizes teamwork with a large shape labeled *teamwork skills* that is located directly under *multimedia design skills* and above the four other subtopics.

Instructional design

Like Student 1's POST representation, Student 2-POST does not provide specific references to steps in the instructional design process. This supporting evidence indicates that this student, like Student 1, had internalized the core tenets of instructional design into the entire process.

Discussion and implications

This study compared students' drawings of their expressed mental models of multimedia design and development from a pre-course and post-course perspective. This study was not designed to offer a quantitative analysis of students' mental models, but rather to indicate qualitatively the potential for use of students' drawings of their own mental models for evaluating their perceptions about the necessary skills to master complex instructional design tasks. This population of students is admittedly small and self-selected; however, there are four implications for instruction that are suggested from this study and that could be applied in larger contexts.

First, the students' drawings were useful in showing a marked change in their expressed mental models of collaborative design and development from the beginning of the course to the end of the course nine months later. The overall comparison of pre- and post-course representations of their expressed mental models indicated a change from a linear, individualistic, and skills-based model to a recursive, collaborative, and team-oriented model. The general structure and organization of the mental models in the drawings changed from isolated and individualistic representations to collaborative and team oriented processes. The change in structure suggests that the mindset and attitudes of the students also changed from one of skills in isolation to one of teamwork and collaboration. Knowledge constructs in the representations changed from a focus on small, isolated units and individual parts to a focus on the whole, a cognitive model that included the big picture. Like Cainey et al. (2012), Katz et al. (2011), and van der Veen (2012), I found that the use of drawings to reveal students' thinking about the collaborative design and development process was an informative and rich data source.

The second implication is that understanding students' expressed mental models can be invaluable for instructors in designing appropriate learning strategies and providing a supportive learning environment. Since mental models are internalized, developing a process for analyzing changes in them may help us gain a better understanding of student needs, and help facilitate the learning of multimedia design and development. Instructors of multimedia design and development who are more aware of the role that mental models play in learning ill-structured knowledge such as design and development are more likely to succeed in supporting learners' experiences (Eckert and Bell 2005). Visualization of mental models can help both instructors and students understand the knowledge building process (Yehezkel et al. 2005). For example, the students' drawings presented in this study suggest changes in thinking from linear, individualistic, and skills-based ideas to recursive, collaborative, and team-oriented ideas. Specifically, most students' post-course drawings do not provide specific references to individual steps in the instructional design process. Although this seems like a glaring omission, it may support the proposition that the core tenets of instructional design had become internalized and automatic during the process of the course, and thus did not come to consciousness when the students constructed the post-course drawing. The questionnaire that students completed on the first night of class indicated that they felt more proficient at the beginning of class in instructional design-related skills such as "using a flowchart," ($m = 3.09$) and "organizing content," ($m = 3.09$), but individual instructional design skills such as these were not included in post-course drawings. Instead, teamwork and value skills such as cooperation, shared responsibility, and communication are shown in many drawings.

Third, drawings can provide another tool for assessing students' understanding and how they process information. Drawings may capture a level of richness that may be missing from essay methods, product assessment, or class evaluations. In addition, van der Veen (2012) noted:

> …assessing students' understanding through drawing forces the instructor to continually use his or her own knowledge flexibly in order to interpret and respond to student thinking, as well as improve his or her own understanding of the concept by seeing how different students understand it. (p. 399)

Finally, graduate students in instructional technology take many isolated courses in learning theory, instructional design and technology applications. The very nature of an academic environment that segments knowledge into separate courses may contribute to students' perception of skills and knowledge in isolation. As evidenced in the pre-course representations, students' prior knowledge is often ill defined and incomplete. A critical factor in designing an experience therefore is the careful, planned integration and practice of all three of these strands: learning theory, instructional design and technology applications. Project-based courses such as the one described in this study may provide this type of integration in an authentic context. It is important to determine however, whether students have actually achieved the objectives of this experience. Understanding the change that occurs during this type of experience can help instructors understand what students have accomplished in relation to thinking, knowing, and learning. This understanding can help us improve and support teaching and learning experiences in multimedia design and development.

Limitations

This finings of this study must be considered in light of its limitations. First, the sample was small, which limits the generalizability of the findings. Second, the students could have been influenced by the questionnaire of self-reported instructional design skills, multimedia skills, and team experiences that I administered on the first night of class. The purpose of the questionnaire was to help me put the students into groups of equal skill sets, but it could have primed them to think about certain skills named in the questionnaire. These skills could have been incorporated into their mental models and expressed in the pre-course drawings. Finally, only one data source, the students' drawings, was used in this study. Suggestions for using other data sources is described in the next section on future research.

Future research

The data presented here suggests that changes in mental models could usefully be explored with more controlled methods. More data about the representations themselves could provide added evidence about meaning and leave less interpretation to the researcher. It could be helpful to ask students to explain their representations. Chapman et al. noted that, "… without the opportunity to talk to all students individually, the intended meaning of their drawings may be vague, unclear, and open to misinterpretation" (p. 119). Soliciting student interpretations of their representations could be accomplished orally either as part of peer group discussion or individually one-on-one with the instructor. Van der Veen (2012) solicited feedback from her physics' students about their drawings to inform her analysis and evaluation. Students could also write explanations of their representations, and the texts could also be analyzed using methods that capture and create conceptual representations (Ifenthaler 2010; Johnson et al. 2009). Students could also be asked to describe what differences they see in the pre- and post-course maps using an interview protocol.

In future studies, the drawings could be analyzed based on their broad representation forms. For example, there seem to be three basic styles of drawings represented in this study: (1) spider-type maps in which concepts are illustrated in oval shapes and connected by lines, (2) artistic representations, and (3) multi-dimensional maps that show higher order relationships. Although this study did not attempt to examine broad styles in the drawings, it would be valuable to see if pre-course and post-course drawings maintained a similar style that could categorize a stable pattern of thinking across time. The analysis of the drawings also did not look at whether the team members, as a group, exhibited any similar characteristics in their drawings. For example, did the members of one team demonstrate more concepts about collaboration in their drawings than another?

It could be helpful to categorize the representations based on a combination of drawing styles and learning styles. Van der Veen (2012) placed the drawings in her study into categories based on learning preferences such as those described by Felder (1993) and Felder and Silverman (1988). For example, she described the "abstract-representational" style with the defining markers of "abstract symbols with a one-to-one correspondence between the symbol and the concept being represented" and the Felder & Silverman (1988) learning style characteristics of "intuitive, visual, deductive, reflective, sequential" (p. 376). Other related data might include examining possible changes in learning style during the same time-period using other measures of learning style (e.g., Learning Style Inventory).

The solicitation of the drawing could also be embedded in a larger framework that includes questions like, "What design process do you use when creating multimedia?" in written or interview format. Vosniadou and Brewer (1992) used a questioning technique to elicit children's concepts about astronomy. The question, "Can you draw a picture of the earth?" was part of an interview process that included 48 questions. Depending on what the children drew, the researcher asked follow-up questions such as, "Is this how the earth would look if we were in a spaceship? Subsequent questions included prompts to "add stars, the moon, and the sky" and "where people live" (p. 544).

Finally, more extensive follow-up interviews with the students could provide additional data on how mental models change over time and with experience. Katz et al. (2011) used email to send a series of open-ended questions to a representative sample of preservice science teachers who participated in an internship opportunity and attached electronic scans of their original drawings. Katz et al. (2011) used these questions to investigate the preliminary findings from the analysis of the drawings and to provide a member check on their interpretations. Using email seemed to be a cost-effective and efficient way to collect additional information about the drawings.

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