International Journal of Engineering Education Vol. 29, No. 6, pp. 1564–1579, 2013
Printed in Great Britain

0949-149X/91 $3.00+0.00

How the Design of Presentation Slides Affects Audience Comprehension: A Case for the Assertion–Evidence Approach*

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Engineering educators often create slides for classroom presentations to instruct students. In turn, engineering students often create slides for classroom presentations to demonstrate what they have learned. Given how often presentation slides are projected and viewed by engineering educators and students, those slides should follow principles of multimedia learning to foster high audience comprehension. Unfortunately, Microsoft PowerPoint, which is the dominant program for creating slides, does not incorporate these principles into its defaults. As a result, most educators and students in engineering create slides that violate these principles. To determine the effect of this violation, we compared learning outcomes in 110 engineering students who viewed a technical presentation in which the slides either integrated or violated six multimedia learning principles. The presentation slides that adhered to the six multimedia principles followed the assertion-evidence approach, while the presentation slides that violated the six multimedia principles followed commonly practiced defaults of PowerPoint. Essay responses from the 110 engineering students revealed superior comprehension and fewer misconceptions for the assertion–evidence group as well as lower perceived cognitive load. In addition, stronger recall occurred in this assertion–evidence group at delayed post-test. These findings support the use of the assertion–evidence structure for presentations in engineering education.

Keywords: presentation slides; PowerPoint; assertion–evidence; multimedia learning

1. Introduction

In engineering classrooms, students frequently engage in multimedia learning, defined as learning through the processing of spoken or printed words that are accompanied by images [1]. This learning often occurs during presentations in which instructors or peers project slides that were created by computer programs such as Microsoft PowerPoint. These slides typically contain words and graphics and are accompanied by the presenter's spoken words. Slide-assisted instruction has become a presentation staple in lectures and professional development settings [2–4]. This type of instruction, which also is common in K-12 settings, is often considered by teachers and students as the instructional technology tool of choice [3, 5].

Outside of the fields of educational psychology and instructional design, a gulf exists between multimedia learning research [6–10] and the slides typically created [11–13]. This may be in part because despite the great body of rigorously controlled experimental work, no slide structure has emerged that steers presenters towards using multimedia learning principles as they design their presentation slides. The result is that instructional slides frequently violate principles of multimedia learning theory and cognitive load theory [11].

In this paper, we draw heavily on multimedia learning theory to articulate flaws in common features of the slides typically used by presenters in engineering. We then present an alternative structure that provides clear direction on the integration of multiple principles of multimedia design. To examine the learning outcomes associated with viewing an instructional presentation using slides built from either typical or alternative approaches, we present the results of an experiment in which students learned about a new topic using either default-driven slides (Common Practice, CP) or multimedia principle slides (Assertion–Evidence, AE).

1.1 *Critical principles necessary for effective multimedia learning*

Multimedia learning research has yielded specific recommendations for the temporal and spatial configuration of text, auditory narration, graphics and animations. Six multimedia learning principles are of particular relevance to designing instructional slides. Although they are listed sequentially here, we

* Accepted 2 June 2013.

contend that it is through their collective use that their application is most powerful for educators.

First, the *multimedia* or *multiple representation principle* states that individuals learn more effectively from graphics accompanied by spoken or written verbal information than from verbal information alone [7, 14]. This principle is congruent with dual-route processing mechanisms posited within psychological theories of working memory and comprehension processes, which emphasize the benefits of forming representations in working memory that select and integrate verbal and nonverbal information [15–18]. Second, the *contiguity principle* emphasizes minimizing the separation in both space and time between different forms of information [8, 19]. Doing so reduces the amount of effort required of the learner because the learner works to select and connect relevant informational elements in order to build a coherent mental representation [20]. A third principle, *redundancy,* or the *split attention effect* arises from experimental findings that individuals benefit from complementary but not identical information presented aurally and visually [7, 21]. Specifically, identical verbal information seems to reduce individuals' available working memory capacity. This reduction can be resolved through the use of the *modality principle,* which states that hearing verbal information is more beneficial than seeing the same information presented in text form on the screen [7]. The fifth principle, *coherence*, emphasizes the importance of removing non-essential information in order to help the learner integrate key concepts and relationships [22]. Finally, a sixth principle, *signaling*, encompasses the benefit of providing the learner with cues about the hierarchical structure of the concepts and the overarching organization of the presentation [23].

1.2 Desired outcomes of multimedia learning

The purpose of instructional presentations is often to achieve learning that goes beyond the simple recall of information such that students comprehend relationships among elements or causal processes within a system. For that reason, multimedia learning researchers have sought ways to foster students' problem solving and transfer of knowledge [24]. These outcomes are borne from a central hypothesis of multimedia learning, which is that multimedia instructional presentations can promote the development of mental models, defined as 'dynamic representations or simulations of the world' [25]. In multimedia learning studies, such models involve representations of technical, scientific processes or multi-component systems, such as lightning formation or braking systems. Learners develop the mental model during exposure to the multimedia instructional message and then the effectiveness of the representation is assessed when learners subsequently need to reiterate the correct sequence of system steps or to solve a problem [26–27]. Mental models thus arise from the learner's representation of system components and processes. More accurate mental models are developed when instructional presentations follow rather than violate multimedia design principles [28–29].

Misconceptions can derive from faulty mental models [30–31]. Sources of misconceptions range from naïve beliefs to instructional inaccuracies [32–34]; we propose that an additional factor may be poor instructional design [35]. Specifically, we propose that when instructional slide presentations violate multimedia learning principles, the development of accurate mental models can be compromised, resulting in the development of inaccuracies and misconceptions. This development may lead not only to poorer recall, but also to the articulation of a misconception as the learner explains a sequence of causal events or steps.

An abundance of experimental evidence suggests that learners benefit from presentations in which multimedia learning principles have been adhered to. However, this conclusion stands in stark contrast to the structure of the vast majority of instructional slides, the structures of which are deeply influenced by the default settings of one commonly used slide software program: Microsoft PowerPoint. In the next subsection, we outline specific ways in which this structure violates multimedia learning principles. We then describe features of an alternative structure called the assertion–evidence structure, which integrates six multimedia learning principles and which can also be applied to slide creation in commonly used programs such as PowerPoint.

1.3 Common practice slides

The typical features of many PowerPoint slides highlight how multimedia learning principles are violated. Figure 1 shows the default settings of PowerPoint's master slide, which has undergone relatively few changes since its inception more than twenty-five years ago [36]. Although several slideware programs exist, we focus on the design of slides using Microsoft PowerPoint. The reason is that worldwide about 250 million computers have PowerPoint software installed, and its slides are used to give more than 30 million presentations each day [37]. In addition, PowerPoint has a dominant share of the slideware market—as much as 95% [38], and its default settings wield considerable power in shaping slides that are often created for instructional purposes.

Fig. 1. The default options commonly used as a starting point for instructional slides.

Several aspects of the default slide encourage violation of multimedia learning principles. A first important group of features to note are those that give rise to the slide's topic–subtopic structure. The slide is composed of a short, phrase headline and a text box that calls for a bulleted text list. The phrase headline specifies a general topic, and each bulleted item listed below appears as a sub-topic that is given equal importance through an outline form. Prior descriptive research has assessed the prevalence of this default structure with and without the addition of an image alongside the bulleted list. Estimates of slides following this topic–subtopic structure have ranged from 65% of slides in a sample of presentations designed for professional communication in engineering and science [11], to 80% of slides included with the instructor materials in a sample of introductory psychology textbooks [39]. Because of its high frequency of use, commonly presented topic–subtopic slides that contain a phrase headline and bulleted list, with or without additional images, can be referred to as *common-practice* slides (see Fig. 2 for examples).

Although the common-practice structure has been the subject of much criticism in the field of technical communication [37, 40–41], our paper focuses on the limitations of this structure from the perspective of multimedia learning theory.

According to the principle of signaling, slide headlines should make explicit the structure of the information contained on the slide. However, the phrase headline violates the principle of signaling in three main ways. First, the phrase at the top of the slide indicates the general topic, but not the relation of the topic to other topics, or the positioning of the topic in the overall sequence of instruction. Second, the bulleted list does not aid in signaling between items and constrains the representation of relationships to one type of relationship at a time [12]. Third, the bullets conceal the connection between informational elements such that the learner must make the appropriate connections, or listen and wait for the speaker to explain them. For novices in the content area, the additional work needed to knit together a coherent understanding of the connections between concepts and sub-concepts could increase extraneous cognitive load [42].

The coherence and redundancy principles

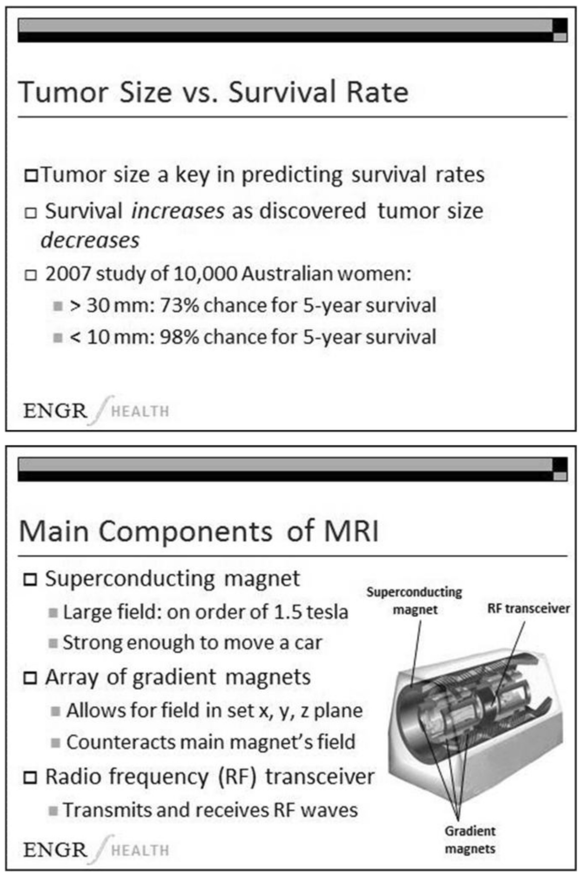


Fig. 2. Examples of common-practice slides. The top slide uses a phrase headline and a bulleted list, and the bottom slide uses a phrase headline, bulleted list, and graphic.

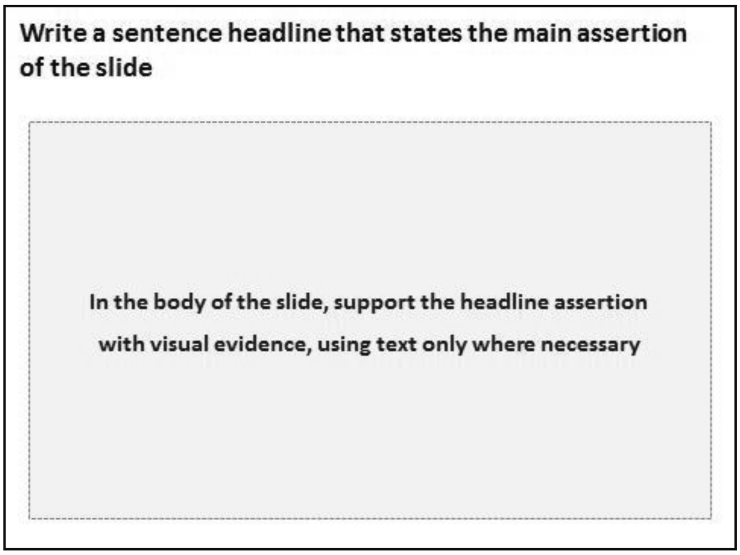


Fig. 3. Default settings for the assertion–evidence slide structure, which features a sentence assertion headline and explanatory graphics with spatially contiguous text.

emphasize the reduction of extraneous text on an instructional slide, particularly if the slide is to be accompanied by a narrative or commentary. As such, following the default setting for a textbox in the body of a topic–subtopic slide encourages the slide creator to violate these two principles. In the case of the coherence principle, including a great deal of non-critical, detailed information in the large default text box makes it more difficult for learners to extract the key point of the slide. This difficulty for learners is particularly likely if the learners do not have a great deal of prior knowledge, which would otherwise allow the distinction of central informational elements from peripheral, non-essential ones [42–43]. In the case of the redundancy principle, text in the text box that is also read aloud by the instructor produces redundancy and potentially increases extraneous cognitive load. Because the default text box in the body of topic–subtopic slides encourages text and often shrinks the font size automatically to allow more and more text to be added, the likelihood of that redundancy is high.

The default setting of PowerPoint encourages the use of text as the primary modality for presenting information in the body of a slide. Images, graphics and other visual media can be included, but are offered as a secondary choice to the bulleted list. This default setting reduces the emphasis on the use of pictorial information and stands in direct contrast to the *modality principle*, which states that images and graphics are beneficial to learning [6]. Descriptive research in this area noted the presence of images on only 40–60% of topic–subtopic slides designed for professional communication in engineering and science [11], and only 33% of topic–subtopic slides from college-level textbook supplementary materials [39]. Moreover, not all images are created equal; the most useful images are those that *explain* rather than simply decorate or even replicate the information presented in the text of the slide [44–45]. When this more rigorous purpose is applied as a criterion, as little as 10% of instructional common-practice slides in a sample of college-level psychology textbooks meet the criterion for the inclusion of explanatory images [39]. Instead, many images simply add situational interest or visual entertainment, thus representing a harmful disconnection between the graphic and instructional purpose of the slide [46].

In summary, common-practice slides violate several multimedia learning principles. The use of the default settings and minor variants thereof is unlikely to contain statements or images that promote the clear presentation of connections among concepts. The application of multimedia principles to this structure reveals its inherently problematic nature, if the goal of the instructional presentation is to allow learners to build a coherent understanding of a system, process, or sequence of events.

1.4 Assertion–evidence slides

The assertion–evidence (AE) slide structure was initially developed for scientific, engineering, and business communication purposes [47–48], but recent research has focused on its applicability to instructional settings [11, 39–40, 49–50]. The structure replaces the phrase headline with a succinct sentence that contains the main declaration or *assertion* of the slide. The body of the slide is then used to visually depict *evidence* that supports, explains, organizes or interprets the headline. Visual evidence can include pictures, graphs, tables, diagrams and words arranged visually [47]. The default template for the assertion–evidence structure is shown in Fig. 3. Shown in Fig. 4 are examples of the assertion–evidence structure that present the same content as the common-practice slides of Fig. 2.

The most striking departure from the common-practice slide structure is the absence of a topic–subtopic format. Instead of having a phrase headline, the assertion–evidence slide structure calls for a sentence headline that makes explicit the main message or assertion that the instructor wishes to make. This thesis statement in the headline acts as an anchor that the learner can use to interpret the informational interactivity displayed in the body of the text. While at first glance the sentence headline might appear to violate the multimedia principle of redundancy, this sentence is a single-sentence summary of the slide that reinforces, on average, ten spoken sentences [47]. The result is the *simultaneous application of the principles of signaling, coherence and redundancy*, because the headline acts to specify relations among key concepts and encourages the instructor to represent only critical concepts or relations.

The second major structural difference between the CP and AE slide structures is the absence of a bulleted list. In the AE structure, explanatory images are encouraged to provide evidence to support the sentence heading assertion. Because the headline specifies a key assertion, finding or proposition, the slide creator is compelled to use explanatory and not decorative or partially representational images. In essence, this feature encourages *congruence with the modality principle*. It also steers the instructor from violating the redundancy principle because the instructor's verbal presentation explains rather than repeats the slide content.

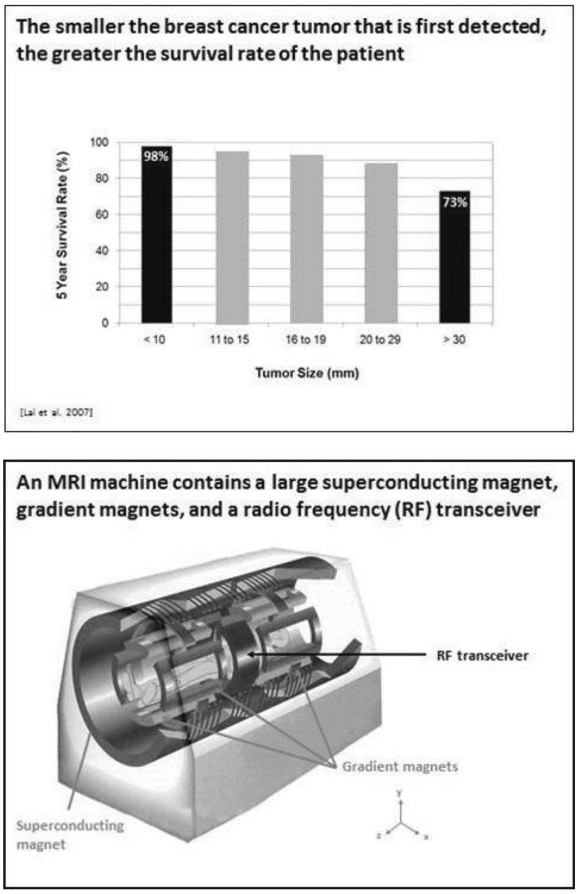


Fig. 4. Examples of assertion–evidence slides. Note that these slides present the same content as that found in the common-practice slides of Fig. 2. Also note that the bottom slide includes a sequence of layers to highlight features of the scanner. Shown here is the last layer, which emphasizes the RF transceiver.

1.5 Prior research on presentation slide elements

Multimedia learning research, such as [51], has often used slideware to present stimuli, but studies have typically focused on the learning outcomes associated with specific manipulations of features that represent individual principles. Less attention has been paid to investigations of the value of integrating principles using a consistent slide template, although findings from studies that varied slide content and structure are relevant. For example, in their study of college student learning of Newtonian mechanics, Wiebe and Annetta [46] examined the effect of high and low text density and high and low text–graphic integration. The study also incorporated a violation of the redundancy principle as students either read silently or viewed a narrated slide presentation for each condition. Although no post-test differences in knowledge were found, eye tracking data revealed differences in visual attention for learners in the narrated condition, which also included dense text. In this case, learners spent increased time viewing the content of the slide, but reduced their visual attention to the slide text. This finding suggests the learners' use of a strategy designed to minimize the otherwise detrimental impact of redundancy. Similarly, other studies support the use of explanatory images on instructional slides. Tangen *et al.* [52] showed ninety college students a 15-minute presentation accompanied by 184 slides. One third of the presentation incorporated text-relevant images, one third incorporated text-irrelevant images, and one third contained text only. Scores on an immediate post-test were lowest for items pertaining to the text-incongruent image slides. This finding suggests that incongruence created additional workload for the learners as they sought to comprehend the information.

Neither of the previous studies explicitly manipulated slide structure in a manner that applied multimedia learning principles to instructional settings. To date, the most ecologically valid test of this approach was conducted by Issa *et al.* [53], who investigated changes in medical students' learning about the clinical condition of shock. Slides for the prior year's lecture, which reportedly consisted of topic headings with bulleted text and additional graphics, were used as the basis for the comparison with learning from a lecture in which slides reportedly consisted of sentence headings, arrows to signal critical aspects of graphics, and sparing use of text. Students who participated in the revised lecture scored higher on post-lecture assessments. Presumably, these features increased the alignment with principles of coherence, redundancy and signaling.

While promising, the results of this and other studies do not provide sufficient detail to yield recommendations about an ideal replacement slide template. More research is needed to identify and investigate the effectiveness of using a slide structure that applies design principles in a consistent manner [52]. With this goal in mind, the purpose of our study was to investigate the learning outcomes associated with the use of either common practice, topic–subtopic slides or assertion–evidence slides, in order to be able to assess the relative impact of structure that consistently integrate or violate multimedia principles of learning.

1.6 Research questions

One primary and two secondary research questions were posed. The primary research question was as follows:

> What learning benefits occur from a presentation in which multimedia learning principles are simultaneously applied and integrated into each slide, compared with a presentation containing identical informational content but in which these principles are violated?

The guiding hypothesis for the study was that viewing a presentation composed of slides that explicitly incorporate multimedia learning principles would result in superior comprehension and retention compared with a presentation that used slides reflecting typical usage and principle violation. This hypothesis can be further divided into statements about the duration of the predicted benefit of the slides designed using multimedia learning principles and the type of learning that may be evident. We predicted that students in the assertion–evidence condition would demonstrate superior learning outcomes immediately after the presentation as evidenced by higher post-test scores for questions requiring inference generation and reasoning. Further, we predicted that students in the assertion–evidence condition would write a higher quality essay. A related expectation was that participants who viewed the assertion–evidence presentation would be less likely to articulate misconceptions. Finally, we predicted that participants in the assertion–evidence condition would retain specific details of the process described in the presentation, such that they would recall these details more frequently than participants in the common-practice group after a ten-day delay.

The secondary research questions were as follows.

> Are differences in presentation type reflected in participants' ratings of the mental effort required to understand the information?
>
> Are differences in presentation type reflected in participants' perceptions of how they viewed the presentation slides and its accompanying narrative?

Because of compatibility between instructional design techniques associated with lowering cognitive load and the structure of assertion–evidence slides, we predicted that assertion–evidence group participants would report lower mental effort [54–55]. In addition, we were interested in whether participants' subjective experiences of the presentation varied in relation to the perceived attention paid to the images, the text and the narration.

2. Method

2.1 Participants

One hundred and ten undergraduate engineers (67 males, 43 females) were recruited from a communications course for engineering students at a large public university in the northeastern portion of the United States. Almost all of the students were of traditional college age. Students were offered a small amount of extra credit towards their course grade in return for their participation. Participants were randomly assigned to assertion–evidence or common-practice presentation conditions. Participants were not aware of any differences between the sessions and were not aware of the experimental manipulation. In total, fifty-nine students viewed the assertion–evidence presentation and fifty-one students viewed the common-practice presentation.

2.2 Materials

Based on the results of a pilot study, the topic of magnetic resonance imaging (MRI) for detecting cancerous tumors was chosen. This topic met multiple selection criteria. First, the topic represents a system of inter-related components that work together in a predetermined sequence in order to achieve a specific outcome. Because eight distinct steps are needed to create a three dimensional scan of the human body, the technical content of the topic was challenging to the participants. Also, because several of these steps are not intuitive,

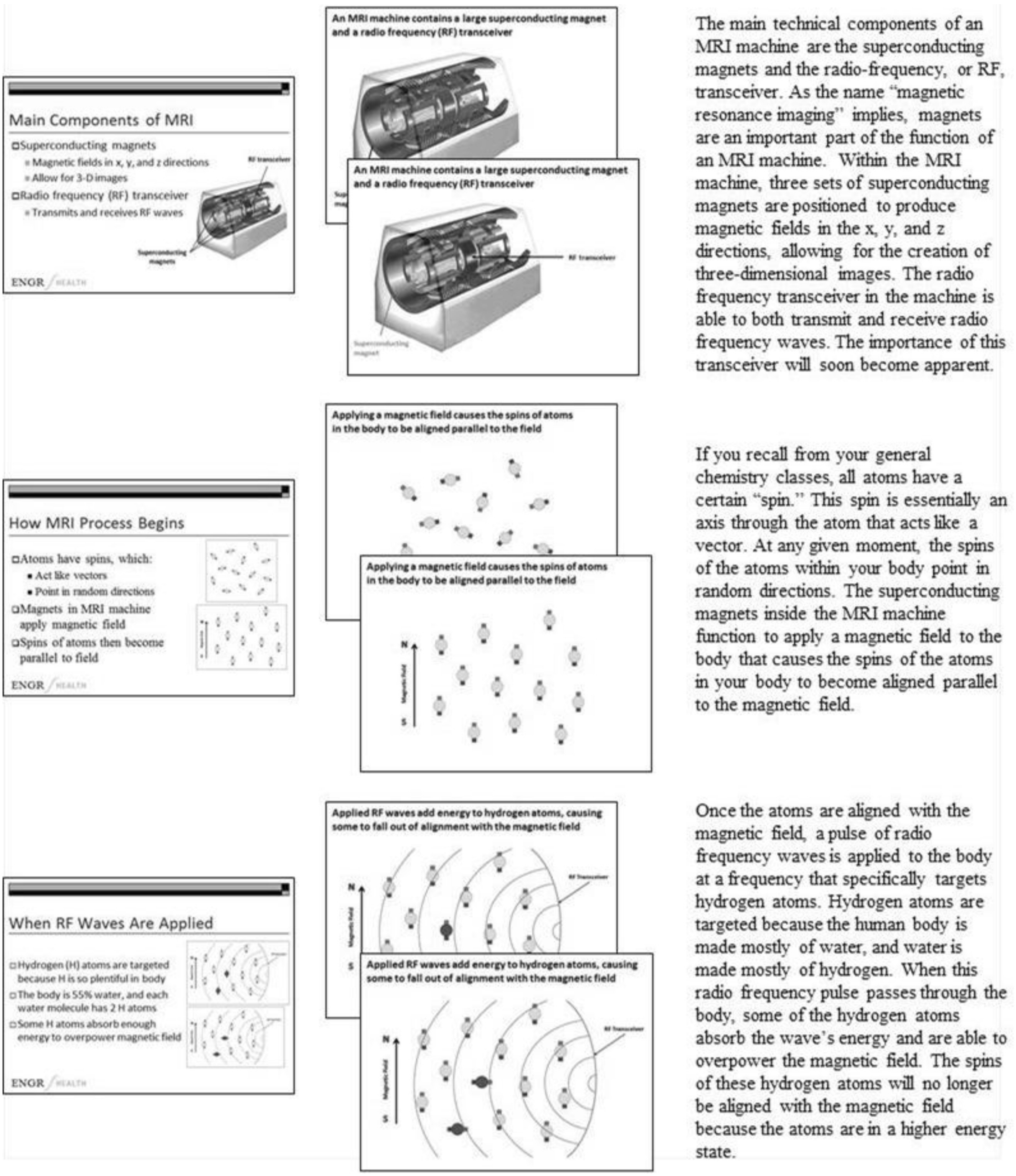
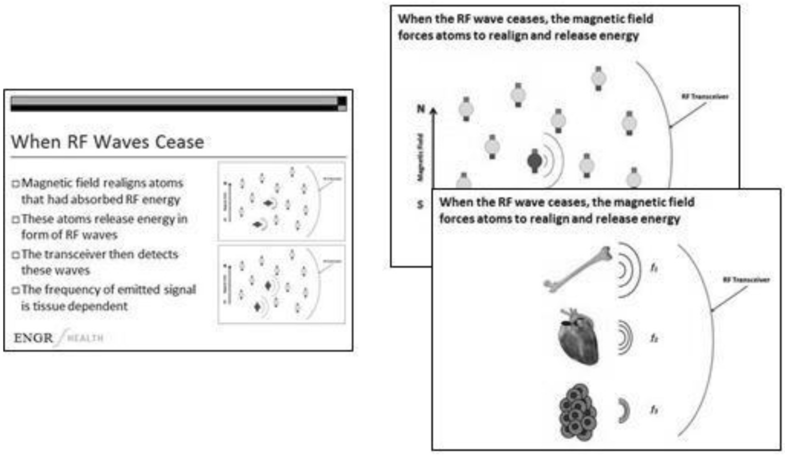


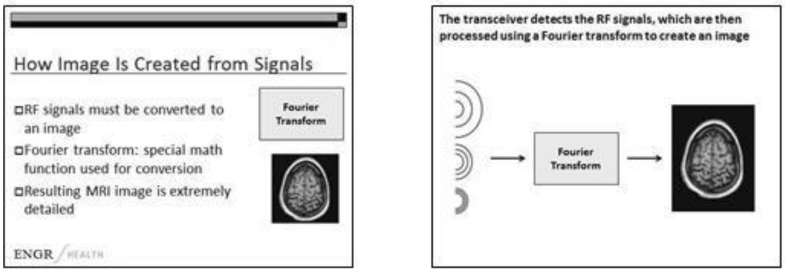
Fig. 5. Comparison of selected common-practice slides (left) and assertion–evidence slides (middle) with the accompanying script (right). These slides present the process of magnetic resonance imaging.

participants would have to understand the presentation to correctly relate that process in an essay. The systemic, structural content of the topic of MRI scanning is therefore somewhat parallel to the brake system or lightning formation sequence used in much of Mayer's work [1]. Accordingly, the presentation included a simplified description that pilot testing revealed was appropriate for college students majoring in science or engineering, but who were otherwise unfamiliar with nuclear medicine and imaging techniques. In addition, the technical process of MRI is based on principles that are included in first-year university physics, chemistry and biology courses. For that reason, even though the participants were unlikely to have specific prior knowledge of how MRI works, the undergraduate engineering students, who were the participants in the study, were capable of understanding the topic.

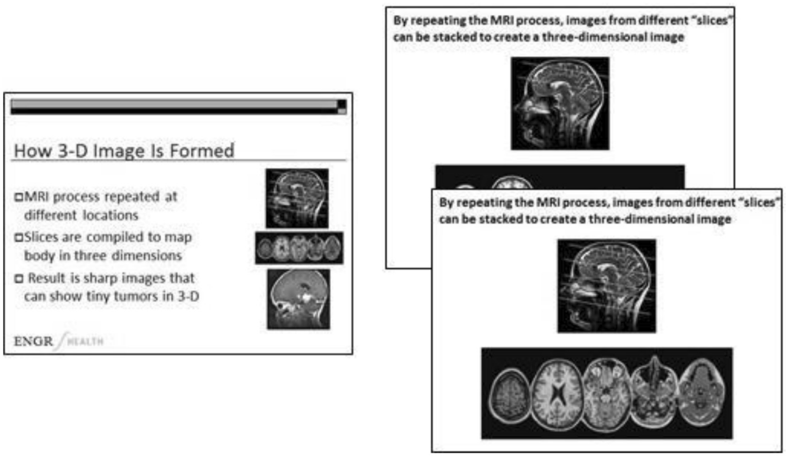
Figure 5 shows the script and several of the slides in each condition. The slides chosen present the



When the pulse of RF waves is turned off, the magnetic field takes over again and forces the atoms that had absorbed the radio frequency energy to realign parallel to the magnetic field. In doing so, the atoms are returning to a lower energy state and must release some energy. That energy is emitted as a radio frequency wave which can be detected by the RF transceiver. The exact frequency of the emitted signal is tissue-dependent. This dependency means that signals emitted from dense tissue such as bone and cartilage will have frequencies different from signals from less dense tissue such as fat and internal organs. Hydrogen atoms in cancerous tumors would emit a signal with a slightly different frequency from all of these.



The radio frequency signals emitted from the body must then be converted into an image. To perform this conversion, the radio frequency transceiver detects the signals and uses a special mathematical transformation, called a Fourier transform, to convert the mathematical signal into an image. The resultant MRI image is extremely detailed.



By repeating the MRI process at different locations, successive images from different "slices" of the body can be compiled to create a three-dimensional image that essentially maps out the body, or in this case, the breast tissue. The use of magnetic resonance imaging for the early detection of breast cancer results in clear, sharp images that can show tiny tumors in breast tissue in three-dimensions.

Fig. 5. (*cont.*)

technical process of magnetic resonance imaging. In developing the eleven common-practice condition slides, two frequently used sub-structures of slide design were used. The first consisted of a topic-phrase heading supported solely by a bulleted list. As found by Garner et al. [11], this structure is found in about 40% of slides from engineering and science presentations. The second structure consisted of a topic-phrase heading supported by a bulleted list and graphics. Garner et al. [11] found that this second structure accounted for 26% of technical instruction slides in engineering and science. For each sub-structure of common-practice slide, the number of words per slide and the percentage of slides with graphics were comparable to statistics gathered previously [11]. In this case, the mean number of words per slide for the common-practice version was 41.5, with 64% of the slides containing relevant graphics. Animation was not used in this condition.

In developing the eleven assertion–evidence slides, we followed specific criteria outlined by Alley [47]. These criteria included having no more than two lines for the sentence assertion headlines, supporting those headlines with relevant graphics, and having as few words as possible for the bodies of the slides. The mean number of words per slide for this condition was 21.2, and each slide in the assertion–evidence condition contained a relevant graphic image. On eight slides in the assertion–evidence condition, portions of a graphic always visible in the common-practice condition appeared on cue when mentioned in the narrated script.

An identical 1000 word narrative script was added to both slide conditions and progressed at the same rate for each condition. The narrative introduced the topic of the presentation and outlined the content. It gave statistics about the prevalence of cancer in the American population and provided information about the structure and function of the MRI scanner components. It then described the sequence of events that allows the scanner's operation to create three dimensional images of the human body (refer back to Fig. 5). The narration also detailed how radio-frequency waves emitted and detected by the scanner differentially affect hydrogen atoms in the body and how these behave in the presence of a magnetic field. The script included information on the relationship between hydrogen atoms and the presence of different types of tissues in the human body, including cancerous tissue. The narration was recorded by a female, native-English speaker. The rate of presentation of content was timed with the progression of the slides. The mean number of words spoken per minute of the narrative was 141. Regardless of condition, the presentation lasted eight minutes.

2.3 Procedure

Each participant attended one experimental session in a classroom equipped with computer projection and audio capabilities. Following the informed consent procedure, participants were told that they were to view a presentation and pay careful attention to its content. The presentation, consisting of the slides with the pre-recording accompanying narration, was then shown. Immediately after the conclusion of the presentation students were given a prompt on a sheet of paper, instructing them to write an essay describing the parts of an MRI machine and their role in the detection of cancerous tissue in the human body. Following the essay, for which 30 minutes were permitted, participants spent 10 minutes providing basic information about themselves such as gender, course section, college major and semester standing. Then participants also completed seven Likert scale questions asking them about their attentional focus and degree of perceived mental effort during the presentation. Finally, participants completed multiple choice questions that were designed to assess recall of details and facts and the ability to understand MRI processes in a coherent sequence.

One week after the experimental session, in the regular classroom setting, students were given an unexpected delayed post-test. The delayed post-test consisted of 17 sentence completion questions. Of these, five questions were designed to assess retention of detailed information and twelve questions were designed to assess understanding of the sequence and purpose of MRI processes. Example questions included recalling what percentage of people in the United States would contract cancer in their lifetime (simple factual recall) and what occurs after the magnetic field causes alignment of spins in the patient's body (complex level).

2.4 Data scoring

All scoring was conducted in a blind manner. A detailed rubric was developed for scoring the essays and is included within the script (see Appendix). Essays were scored by two authors with one author continuing to score the remaining essays after inter-rater agreement was established using the first 25 essays. Inter-rater agreement was calculated by dividing the number of statements scored the same way by the total number of statements that were scored. Agreement at the 90% level was reached between the first and second authors prior to the remaining essays being coded by the second author.

To assess differences in the participants' ability to recall and explain specific segments of the MRI process, separate sub-totals were generated per segment of the presentation. These separated sub-totals were then summed to create a total score for the essay. These five sub-totals reflected participants' ability to correctly explain (1) the parts of the MRI machine, (2) the role of the superconducting magnet and radio-frequency transceiver in the MRI process, (3) the effects of radio-frequency waves on atomic structures in the body, (4) the role of tissue density in permitting cancerous tissue to be detected and (5) the method of computational analysis used to generate MRI images. As such, each sub-total represented a discrete step that the participant would need to be able to mentally simulate in order to describe the process of MRI scanning correctly. The sub-totals provide an assessment of the structure of the participant's mental model representation of the process.

A separate sub-total score was calculated to represent the degree to which participants included statements that captured the dynamic aspect of the multi-step process of MRI image generation. These sub-totals may be interpreted as an assessment of the ability of the participant to dynamically connect each component of their mental model representation. For example, this score increased as participants made statements about the correct sequential order of dynamic processes such as the *transmission* and *reception* of radio-frequency waves, *alignment* of atoms with the magnetic field, *movement* of atoms to a higher and lower energy state depending on radio-frequency absorption, and the later *release* of energy by excited atoms in the form of a wave.

Essays were also scored for the presence of misconceptions. Misconception scores were calculated separately from the participant's total score for the essay, such that the presence of misconceptions did not create a penalty other than would be incurred naturally by not recalling the information correctly. Misconceptions were defined as statements that revealed a misunderstanding of the processes involved in MRI scanning, such as stating that the cancer cells rather than the hydrogen atoms become aligned with the magnetic field, or that the superconducting magnetic field is switched off when the radio-frequency waves are emitted. Participants with major misconceptions presented not only an inaccurate but an alternative explanation for that step in the overall MRI process. Minor misconceptions were categorized as statements that represented an incomplete understanding, such as writing that only hydrogen atoms would be affected by the magnetic field.

Immediate post-test multiple choice questions were scored dichotomously. Multiple choice questions were aggregated into three groups according to whether they required the recall of factual and statistical information (5 questions), process-related information (4 questions), or the generation of inferences and simulations of processes implicitly contained in the presentation (2 questions). One multiple choice question was dropped from the aggregation process because of a ceiling effect.

To investigate differences between groups, we conducted a delayed post-test. This delayed post-test consisted of 10 fill-in-the-blank questions designed to assess students' recall and understanding of the functions of the main components of the MRI scanner and the step-by-step processes used in scanning the human body in order to create three dimensional images. Questions paralleled the order in which concepts were presented in the original presentation. Delayed post-test sentence completion questions were scored according to a 0–2 point system. One point was given for a partially correct response.

2.5 Data analysis

Parametric inferential statistical tests were used to determine the nature of relationships between self-ratings and learning outcomes, and differences between conditions and learning outcomes. Correlations, independent samples t-tests, and Analysis of Variance were conducted using SPSS 18.0 for Windows. There was no effect of gender on any of the outcome measures. Data were collapsed across gender for each condition.

3. Results

The primary research question sought to determine comprehension and learning differences between participants who viewed the assertion–evidence slide structure presentation and those who viewed the common-practice one. Analyses of the essay and multiple choice responses were used to inform the hypothesis that as a group, participants who viewed the assertion–evidence presentation would show superior comprehension than those who viewed the common-practice presentation.

3.1 Evidence of learning as demonstrated by essay responses

3.1.1 Total scores

The essay prompt required students to write a detailed description of how the MRI scanner functions to create three dimensional images that can be used to detect cancerous cells in the human body. Total scores were used as the dependent variable in an independent samples t-test, which revealed significant differences in favor of the group of students who experienced the assertion–evidence presentation, $t_{(93.43)} = 3.67$, $p < 0.001$, Cohen's $d = 0.81$. Descriptive statistics are presented in Table 1.

3.1.2 Recall of correct sequence of the MRI process

Essays were also scored in subsections that related to specific parts of the presentation. These parts also conformed to steps in the MRI process, although the components of the MRI machine were also grouped as a subsection. ANOVA analysis revealed significant differences in favor of the assertion–evidence condition for four out of five subsections (see Table 1). For the subsection where students needed to describe the parts of the MRI machine accurately, $F_{(1,110)} = 19.32$, $p < 0.000$, Cohen's $d = 0.82$. For recall of the roles of magnets and the transceiver, $F_{(1,110)} = 6.07$, $p = 0.015$, Cohen's $d = 0.39$. For the effects of radio-frequency waves on atomic structures in the body, $F_{(1,110)} = 6.45$, $p = 0.013$, Cohen's $d = 0.46$. For the role of tissue density in permitting cancerous tissue to be detected, $F_{(1,110)} = 4.178$, $p = 0.043$, Cohen's $d = 0.34$. Group differences in the participants' ability to describe the computational analysis used as the final

Table 1. Descriptive statistics for immediate learning outcomes as evidenced by essay test

	Maximum possible score	Presentation condition			
		Common-practice (n = 51)		Assertion–Evidence (n = 59)	
		Mean	Std. Dev.	Mean	Std. Dev.
Total essay score	15	6.73	4.21	9.39**	3.26
Segment scores:					
Parts of MRI machine	4	3.15	1.66	4.30**	1.08
Effects of gradient magnets	5	1.99	1.23	2.51**	1.02
Effects of changes in magnetic field on subatomic structures in the body	2	0.96	0.78	1.32*	0.72
Role of tissue density in permitting cancerous tissue to be detected	1.5	0.60	0.49	0.78*	0.46
Method of computational analysis used to generate MRI images	2	0.93	0.60	1.07	0.54
Sub-total score: dynamic aspects of MRI process	7.5	3.38	2.16	4.53**	1.60

*p < 0.05; **p < 0.01.

Table 2. Descriptive statistics for major and minor misconceptions by condition

	Presentation condition			
	Common-practice (n = 51)		Assertion–evidence (n = 59)	
	Mean	Std. Dev.	Mean	Std. Dev.
Minor misconceptions	0.39	0.72	0.22	0.53
Major misconceptions	1.04	1.21	0.51**	0.88
Total misconceptions	1.54	1.29	0.98**	1.06

*p < 0.05; **p < 0.01.

step in the process of generating MRI images were not statistically significant.

3.1.3 Representation of the dynamic nature of the MRI sequence

A score reflecting the accurate use of dynamic or causal terms was derived from participants' essays as an attempt to capture the degree to which participants' mental models allowed them to simulate or recreate key causal processes that linked one sub-step in the MRI process to the next. The score represented an aggregate across all segments of the MRI image generation process. An independent samples t-test revealed significantly higher scores for participants in the assertion–evidence condition compared with the common-practice condition, $t_{(91.05)} = 3.49$, $p < 0.001$, Cohen's $d = -0.60$. The assertion–evidence slide presentation appeared to foster more accurate representation of the dynamic aspects of the steps in the MRI process.

3.1.4 Presence of misconceptions

Essays were also examined for the presence of misconceptions. An independent samples t-test was conducted using the total number of misconceptions as the dependent variable and presentation condition as the independent variable. Repeated measures ANOVA revealed that common-practice participants were found to have significantly higher scores for total misconceptions than assertion–evidence participants, $F_{(1,108)} = 9.84$, $p < 0.01$, partial $\eta^2 = 0.08$, Cohen's $d = 0.47$. There was also a main effect of type of misconception, with major misconceptions being less frequent than minor misconceptions, $F_{(1,108)} = 14.71$, p < 0.001, partial $\eta^2 = 0.12$. Descriptive statistics for major, minor and total misconceptions for each condition are shown in Table 2. Although the mean scores for major and minor misconceptions appear to indicate an interaction, this interaction was not statistically significant, $F_{(1,108)} = 2.19$, $p > 0.05$. Overall, these results demonstrate that participants who viewed the assertion–evidence presentation were less likely to include misconceptions in their essays than participants who viewed the common-practice presentation. This finding is supportive of the directional hypothesis that instructional slides designed with integrated multimedia learning principles in mind foster the development of correct mental models of complex processes.

3.2 Evidence for short-term and delayed learning

3.2.1 Immediate post-test

ANOVA was used to investigate group differences in performance on multiple choice questions using presentation condition as a between subjects factor and question type as a within-subjects factor. No main effect was found for presentation condition, $F_{(1,108)} = 1.21$, $\eta > 0.05$. Within subjects, a main effect of question type was found, $F_{(2,218)} = 6.94, p <$

0.001, partial $\eta^2 = 0.01$. Between subjects, an interaction was found between question type and condition, $F_{(2,108)} = 5.68$, $p < 0.01$, partial $\eta^2 = 0.06$; a significant effect of presentation condition was found for higher cognitive level questions requiring inference and simulation, $F_{(1,110)} = 11.25$, $p < 0.01$, partial $\eta^2 = 0.09$. These results suggest that immediately after viewing the presentation, students in the assertion–evidence condition were no less likely to recall factual, statistical or explicitly presented process-related information than students in the common-practice condition.

3.2.2 *Delayed post-test*

The delayed post-test items required sentence completion in a manner that paralleled the sequence of steps involved in the MRI process as detailed in the narrated script that accompanied the slides ten days earlier. From these completed sentences, a total score was calculated. Total score was used as the dependent variable in an independent samples t-test, which revealed significant differences in favor of the students in the assertion–evidence condition, $t_{(93)} = 4.34$, $p < 0.001$, Cohen's $d = 0.89$. Descriptive statistics associated with this finding are included in Table 3. This finding is supportive of the hypothesis that the relative benefit of experiencing assertion–evidence slides persists over time.

3.3 *Participants' ratings of assertion–evidence and common-practice slides*

3.3.1 *Perceived mental effort*

Perceived mental effort required to comprehend the information was used as an indicator of subjective cognitive load. Slide presentation condition significantly impacted students' perceived mental effort. On a 7-point scale where a 7 indicated very high effort, the mean self-rating for students in the common-practice condition was 3.61 (*SD* = 1.11) and the mean self-rating for students in the assertion–evidence condition was 3.01 (*SD* = 1.17). An independent samples t-test revealed that students in the common-practice condition gave higher average ratings for their perceived mental effort required to learn the information than did students in the assertion–evidence condition, $t_{(109)} = -2.71$, $p < 0.01$, Cohen's $d = -0.50$. Self-rating of mental effort was also significantly and negatively correlated with learning outcomes as measured on the essay test, even when controlling for self-rating of prior knowledge, $r = -0.23$, $p < 0.05$. That is, participants who reported high mental effort tended to show poorer learning outcomes than participants who reported low mental effort. This case occurred regardless of the amount of prior knowledge about the topic area that the participant reportedly had, suggesting that presentation condition impacted ratings regardless of prior knowledge about the topic.

3.3.2 *Self-rated prior knowledge*

Self-ratings of content knowledge were included in an attempt to address the issue that post-exposure indicators of learning outcome may be influenced by prior knowledge. On the 7-point scale, with 7 indicating that all of the information presented was already known, the mean response was 2.58 (*SD* = 1.24). Prior knowledge ratings did differ significantly between conditions, $t_{(108)} = -2.71$, $p < 0.001$, with participants in the assertion–evidence condition rating themselves as having higher prior knowledge of the topic. The mean rating was 2.87 (*SD* = 1.36) for participants in the assertion–evidence condition. For participants in the common-practice condition, the mean rating of prior knowledge was 2.24, (*SD* = 1.00). However, simple correlation analyses revealed that self-rating of prior knowledge was not correlated with post-test learning outcomes. Self-rating of prior knowledge was correlated with perceived mental effort, $r = -0.22$, $p < 0.05$. In both conditions, participants who gave themselves lower prior knowledge scores were more likely to report that higher mental effort was needed to comprehend the presentation.

Table 3. Descriptive statistics for immediate and delayed learning outcomes as evidenced by multiple choice and fill-in-the-blank tests

		Presentation condition			
		Common-practice (*n* = 51)		**Assertion–evidence (*n* = 59)**	
	Maximum possible score	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Immediate multiple choice post-test					
Items assessing recall of facts and statistics	5	4.14	1.06	3.80	1.05
Items assessing comprehension of processes	4	3.23	0.84	3.47	0.75
Items assessing inferences and simulation	2	0.86	0.66	1.32**	0.75
Delayed fill-in-the-blank post-test items assessing comprehension of processes[1]	10	5.52	2.69	7.77**	2.35

*$p < 0.05$; **$p < 0.01$; [1] CP $n = 42$; AE $n = 53$.

Table 4. Descriptive statistics for participants' perceptions of the slide presentations

	Presentation condition Common-practice (n = 51)		Assertion–evidence (n = 59)	
Perceptions of the slide presentation[1]	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Perceived balance of attention between slide and narration	3.84	1.36	3.69	1.24
Helpfulness of the written text on the slides	4.49	1.63	4.02	1.61
Appropriateness of the amount of text on the slides	4.41	1.00	3.87**	0.79
Helpfulness of the graphics	5.45	1.39	5.83	1.17
How much of the text did participant read	5.31	1.29	5.50	1.66

*p < 0.05; **p < 0.01; [1] Rated on a 7-point Likert scale.

3.3.3 Attention to specific slide elements

Participants rated specific aspects of their subjective experiences of the slide presentation. Descriptive statistics are shown in Table 4. Responses were broadly uniform between conditions, with the exception of ratings of whether or not slides had an appropriate amount of text on them. Interestingly, the mean rating of the appropriateness of the amount of text was lower for the assertion–evidence condition than those in the common-practice condition, $t_{(109)} = -3.20$, $p < 0.01$, Cohen's $d = -0.60$. Participants did not report different attentional focus or different perceptions of slide features, except for the appropriateness of the amount of text on the slide, which favored the common-practice condition. This lack of difference in perceptions exists despite differences in learning outcomes.

4. Discussion

This study compared the effect on learning of viewing a slide presentation that either integrated multimedia learning principles or one that violated those principles. In the assertion–evidence condition, the modality, multimedia, coherence, signaling and redundancy principles were simultaneously applied to each slide through the use of a sentence assertion heading, explanatory diagrams and images, and sparing use of slide body text in close proximity to the images. In the common-practice condition, slides were modeled after the structures most easily created using PowerPoint default settings and most frequently found in engineering and scientific presentations [11–12]. The topic of the presentation required learners to create a relatively complex mental representation of a sequence of causal events, and the form of assessment required learners to be able to write an essay describing the events as well as answer multiple choice and fill-in-the-blank questions at immediate post-test and delayed post-test, respectively.

4.1 Assertion–evidence slides as a means for promoting coherent mental models

The findings of this study provide support for the *simultaneous* application of multiple multimedia learning principles to slide design and suggest that the adoption of the principles in this manner has both immediate and long lasting benefits for learners. In this experiment, participants who viewed the assertion–evidence presentation outperformed participants who viewed the common-practice presentation in several ways. First, participants in the assertion–evidence slide condition were able to write significantly higher quality essay responses in response to an open ended question that required them to recreate all of the steps in the multi-step process of conducting an MRI study of the human body. This finding was revealed by examining group differences in summed scores from an analytical rubric. Participants in the assertion–evidence slide condition were also more likely to accurately recall the details of the structure of the MRI machine and the connections between each sub-step within the process. This finding was established through an analysis of differences in groups' scores on items requiring correct knowledge of specific aspects of the MRI process. Moreover, participants in the assertion–evidence condition were also more likely to be able to correctly describe the dynamic contingencies between one sub-step in the MRI process and another. Significant differences were found in participants' usage of terms and concepts that described the relationships among key elements that are reasonably expected to be included in a mental model [31]. These differences were not achieved at the expense of participants' ability to recall details and factual information about the topic at either immediate or delayed post-test.

Perhaps most notable among these findings, and most closely related to prior research in multimedia learning, is that differences were found in participants' ability to describe specific aspects of the MRI machine and its processes. In a manner that parallels the superior performance of participants in other multimedia learning studies where a principle is introduced and experimentally manipulated, the current study also revealed differences in favor of the principle-congruent condition. However, in this case, the differences favored the assertion–evidence condition in which multiple principles were applied. Viewing assertion–evidence slides appeared to provide an advantage when it came to being able to accurately describe the structure of the MRI machine and when the temporal and causal sequence of events that occur during an MRI study needed to be specified. Situating these findings within the broader context of mental model construction, we might say that the assertion–evidence slides appear to promote learners' ability to construct a mental model that consists of appropriate features as well as an accurate representation of the relationships among those features. This finding is very much congruent with definitions that posit mental models as being coherent mental structures of propositions into which the relations among propositions are inherently represented [26–27]. It is also worth noting that benefits to both propositional detail and relational elements of mental models were present despite the fact that animation features were not employed in either type of presentation. The MRI process was not shown in a dynamic fashion; participants had to simulate the sequence of processes that comprise MRI scans as they wrote their essays. Members of the group that viewed the assertion–evidence slides seem to have been able to do this simulation more consistently. This finding speaks to the potential utility of the assertion–evidence slide structure for helping learners to create accurate mental models that can be used to support reasoning, in much the same way as prior multimedia learning studies, such as [56] have done.

A second contribution to our understanding of multimedia learning through instructional slides comes from our finding that assertion–evidence slides seemed to have a protective effect when it comes to developing misconceptions. In particular, the assertion–evidence group was less likely to misarticulate key causal relationships among system components or process steps. One interpretation is that it is related to the quality of the mental model that was generated during the learning episode. This interpretation is in agreement with prior research that has attributed faulty mental models as one source and manifestation of misconceptions [30–31]. Because misconceptions that arise from faulty mental models are more difficult to remediate than simple false beliefs, it may be that assertion–evidence slides have particular merit during the learning of science topics in which misconceptions can arise. We propose that further research is needed to assess the potential of the assertion–evidence slide structure for such situations.

4.2 The effect of differences in slide structure on perceived mental effort

Participants who viewed the assertion–evidence condition rated their mental effort during the presentation as being lower than those in the common-practice condition. Although this finding arises from an indirect and global measure of cognitive load, we interpret this finding as arising from differences in extraneous cognitive load because the information contained in both forms of the presentation was identical. We believe that this finding reflects a contribution towards understanding how multimedia principles and cognitive load are inter-related. Unlike other research such as [57], the manipulation in the current experiment involved the simultaneous application of multimedia design principles. We speculate that the elimination of redundancy plays a significant role in reducing cognitive load. Further research to uncover which aspects of the assertion–evidence slide structure best support the minimization of cognitive load may be fruitful.

Interestingly, few significant differences occurred in participants' ratings of their experiences of the slide presentations. Assertion–evidence slides were not judged to show more helpful text or more helpful graphics. In the case of the graphics, this finding may arise because of the very similar graphics in both conditions. Where a difference did occur was in the appropriateness of the amount of text on the slides, which favored the common-practice group. This result might conceivably reflect the need for more focused attention on the presentation from the assertion–evidence group. However, this explanation is unlikely, given that this group reported lower perceived mental effort. The finding may instead reflect participants' expectations for the abundant use of text, based on the cultural norm of filling in the large text box of PowerPoint's default master with bulleted lists [11].

5. Conclusions

In this study, we examined immediate and delayed learning outcomes associated with viewing a presentation that used either commonly arranged slides or assertion–evidence slides. The presentations differed in adherence or violation of multimedia learning principles, but were otherwise identical in narration and informational content. Participants who viewed the assertion–evidence slides demonstrated superior comprehension and recall of information, and we propose that this finding is reflective of the way that assertion–evidence slides support the development of accurate mental models.

What has been lacking until now is a clear structure or template that can be used to support multimedia learning during learning episodes that take place using slide-assisted direct instruction. We propose that the assertion–evidence slide structure fills that void and shows promise in improving students' learning from instructional slides.

Acknowledgments—We wish to extend sincere thanks to Dr. Richard Mayer for his helpful comments on an early draft of this paper. We wish to thank Keri Wolfe and Lauren Sawarynski for their contributions to the MRI script and help in running the experiment. We also wish to thank the Leonhard Center for the Enhancement of Engineering Education for their financial support of this work.

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Appendix

Essay scoring rubric

Steps of the MRI process are numbered and in italics. The maximum total score was 15 points.

Superconducting magnets produce a magnetic field in a particular *x*, *y*, *z* direction (2 points). Radiofrequency transceiver transmits rf waves to body receives or detects rf waves from body (3.5 points). After *magnets are turned on*, *the spins of atoms align with magnetic field* (1 point). When *RF transceiver emits energy*, some of the hydrogen atoms move to a higher energy state (2 points). The *spins of these atoms fall out of alignment with the magnetic field* (0.5 points). Hydrogen is targeted because the body is mostly (55%) water and each water molecule has two hydrogen atoms (1.5 points). When *the transceiver stops emitting radio waves*, *the magnetic field realigns the spins of the unaligned hydrogen atoms* and the atoms return to a lower energy state (1.5 points). In returning to a lower energy, *the atoms release energy in the form of a radio wave* (0.5 points). Different types of tissue emit different frequencies. These frequencies depend, in part, on the density of hydrogen in the tissue (1.5 points). *The MRI machine takes these waves* and uses a mathematical formulation called a Fourier transform *to create an image* (1.0 points). Each scan produces a thin image or slice. *The scanning process is repeated to create* additional slices, which are compiled into *a 3-D image* or map (1.0 points).

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