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Exploiting Multimedia in Reproductive Science Education: Research Findings

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Contents

Education in reproductive science is operating from an outdated paradigm of teaching and learning. Traditionally, reproductive education follows the pattern where students read a textbook, listen to instructor presentations, re-read the textbook and class notes and then complete a test. This paradigm is inefficient, costly and has not incorporated the potential that technology can offer with respect to increases in student learning. Further, teachers of reproductive science (and all of science for that matter) have little training in the use of documented methods of instructional design and cognitive psychology. Thus, most of us have learned to teach by repeating the approaches our mentors used (both good and bad). The technology now exists to explain complex topics using multimedia presentations in which digital animation and three-dimensional anatomical reconstructions greatly reduce time required for delivery while at the same time improving student understanding. With funding from the Small Business Innovation Research program through the U.S. Department of Education, we have developed and tested a multimedia approach to teaching complex concepts in reproductive physiology. The results of five separate experiments involving 1058 university students and 122 patients in an OB/GYN clinic indicate that students and patients learned as much or more in less time when viewing the multimedia presentations when compared to traditional teaching methodologies.

Where Are We Today? A Historical Perspective

In the 575 years since the invention of the printing press, the instructional paradigm in reproductive science has remained fundamentally unchanged. The paradigm is that students:

1 are encouraged to read a textbook or other assigned reading material,
2 go to a classroom at a predetermined time and listen to instructor presentations for 50 min or more,
3 study by re-reading the textbook and reviewing the notes taken during the lecture,
4 take a test that determines their grade.

Unfortunately, suitable alternatives have not been widely adopted, which offer opportunities for improvements in science education at the undergraduate level. Most of the classroom interventions (overhead projectors, slide projectors, document cameras, photocopiers and PowerPoint® presentations) that have been introduced during the past 60 years have enabled increased information to be presented in a shorter period of time. The interventions have operated on the erroneous principle that the more information that is presented, the better for the student. Unfortunately, class presentations in reproductive science using these interventions are rarely guided by documented principles of instructional design.

Most of us in the field of reproductive physiology have had little or no training in cognitive theory or how to employ instructional design principles for classroom and other forms of presentations. In short, we have learned to teach by mimicking our teachers (both good and bad) rather than employing the empirical and theoretical educational principles of cognitive and educational psychology. Some of the most relevant principles will be described below.

The outdated paradigm described above needs to change, so that students have alternative methods to learn important concepts in a shorter period of time than that required by traditional classroom lectures. Students are increasingly embracing mobile technology in the form of iPads®, Internet applications and cell phone text messaging. And, they are doing it independent of classroom activities. The technology now exists to explain complex topics using multimedia presentations that utilize digital animations and 3D anatomical reconstructions. These interventions greatly reduce the time of delivery while at the same time improve understanding (Trevisan et al. 2010). Current technology also enables rapid turnaround for the evaluation of student understanding (testing) in a much more timely fashion than current classroom testing procedures, providing essential feedback to students about their performance. Unfortunately, we have not yet generally made the transition from the outdated paradigm to one that is more representative of the new millennium. One may speculate that a reason for the delay in making such a transition is that many professors are 'digital immigrants' and are not comfortable embracing mobile technologies. Professors, especially older ones, may feel threatened that new technologies will erode their classroom authority.

The purpose of this communication is threefold. The first is to describe the principles of multimedia instructional design that are known to result in enhanced learning. The second is to demonstrate the salient instructional design principles using portions of multimedia programmes in reproductive science (sample demonstrations can be viewed at http://www.currentconceptions.com). The third is to describe research outcomes of experiments designed to test the effect of multimedia on learning in reproductive science.

The majority of the content in this paper is derived from the doctoral dissertation of Angela C. Oki at Washington State University. The dissertation is entitled 'Integrating Multimedia Instructional Design Principles with Complex Physiological Concepts in Reproductive Science' (2011).

Multimedia and Effective Learning

In its simplest form, multimedia is defined as presenting information through the use of words and pictures (Mayer 2001, 2005). Multimedia can be employed as traditional classroom lectures or may involve stand alone video presentations to explain concepts. Traditional teaching of physiologic mechanisms has heretofore involved laborious chalkboard drawings or handouts coupled with a verbal explanation. This approach often results in confusion and inevitably the need to repeat explanations. The availability of digital software to capture anatomical detail and produce 3D motion to describe time-related changes holds great promise for explaining complex physiologic mechanisms in reproductive science.

The use of a multimedia can have two primary outcomes. First, with proper instructional design, multimedia coupled with animation can be a powerful learning intervention (Betrancourt 2005). At the same time, there is theoretical and empirical research that indicates that learning can actually be suppressed with excessive verbiage or images (Mayer et al. 1996, 2001; Harp and Mayer 1998; Kalyuga et al. 2000; Moreno and Mayer 2000a,b; Pollock et al. 2002; Mayer and Moreno 2003). In short, for multimedia technology to realize its potential for enhancing learning, the technology must be designed, developed and delivered in specific ways.

The use of multimedia instructional design operates approximately three core assumptions. These are as follows:

- Learners process information utilizing two primary sensory channels (also known as dual coding). These are the auditory and optic sensory systems (Paivio 1986; Clark and Paivio 1991).
- Working memory has limited processing capacity and is easily overloaded (Baddeley 1986; Baddeley 1999). In other words, students can only process a small amount of information per lecture period.
- Meaningful learning occurs best when the learner is actually engaged in processing information (Wittrock 1989; Mayer 2001, 2005). For example, students must actually 'think about' what is being presented rather than robotically taking notes or using a highlighter to visually underscore important points during lecture or laboratory sessions. Further, for most students, the driving force is 'what will be on the test' rather than understanding concepts.

Principles of Effective Multimedia Instructional Design that Apply to Reproductive Science

Instructional design can be defined as the particular teaching method used to present information. In a more complete sense, instructional design involves strategies that are intended to improve presentation methodology with the goal of facilitating learning. These strategies engage the following questions:

- What will the topic be?
- What will the topic order be?
- What visual aids will be used, if any?
- What will be the sequence of presentation?
- How much depth of knowledge will be required?

Unfortunately, most of us base our instructional design for teaching classes on an 'intuitive feel' for what might be effective rather than calling upon documented principles of instructional design that are based on controlled research. In this respect, researchers in the field of cognitive and educational psychology have developed instructional design principles that are effective in promoting enhanced learning. Those principles that have particular applicability to reproductive science are presented below.

PRE-TRAINING-presenting names and definitions before presenting main concepts

Pollock et al. (2002) and (Mayer et al. 2002a,b) demonstrated that by showing how each component of a system functions first, then followed by how the components work together enhances problem-solving for beginning students. For example, when describing the structure and function of the female reproductive system, it is much better to describe each component (ovary, oviduct, uterus, cervix and vagina) independently before attempting to describe how these components function as an organ system that is dependent on hormone secretion and target tissue response.

MODALITY-presenting some information through the optic sensory channel and some through the auditory sensory channel expands working memory

Modality refers to the interplay of auditory and optical sensory systems with regard to how an individual processes information. As an example, students who received diagrams with an auditory explanation spent less time studying a diagram and solving math and medical problems when compared to learners who received diagrams with written explanations only (Mousavi et al. 1995; Tindall-Ford et al. 1997). Further, students learn more from animation that is coupled with narration than students who were presented with information from animation and printed text only (Mayer and Anderson 1991; Mayer and Anderson 1992; Mayer and Moreno 1998; Moreno and Mayer 1999; Kalyuga et al. 2000; Moreno et al. 2001; Moreno and Mayer 2004). In short, illustrations are processed through the visual channel while narration is processed simultaneously through the auditory channel. Information that couples graphic illustrations along with text to be read puts greater strain on working memory than listening to an explanation through narration. Scientific textbooks are limited in this regard because the student reader utilizes the optic sensory input only, rather than coupling optical and auditory inputs. As a result, students tend to minimize pre-class reading and studying because they are easily confused when reading a textbook because of overloading their working memory. Multimedia and classroom presentations circumvent this problem by providing narration that allows for simultaneous engagement of the auditory and optical sensory channels and thus better learning.

COHERENCE-elimination of extraneous information (incoherent information)

Extraneous information is defined as information not related to the primary focus of communication (Mayer et al. 2008). This is probably the most abused instructional design principle in reproductive science. Too often we cloud the understanding of a basic principle or concept by presenting unessential detail. For example, if we want to have students understand the components of the oestrous cycle, we could present the information as follows:

The oestrous cycle consists of two phases. These are the follicular phase and the luteal phase. The dominant ovarian structures in the follicular phase are antral follicles. The dominant ovarian hormone during the follicular phase is estrogen. The luteal phase is characterized by the presence of a corpus luteum and it is the dominant structure. The dominant ovarian hormone is progesterone.

This approach provides a coherent message about the phases of the oestrous cycle, the structures and the primary hormones involved. In contrast, the following example illustrates how the presentation of extraneous information seriously compromises the concept about the phases of the oestrous cycle.

In animals, the estrous cycle consists of the follicular and luteal phases. An exception to this exists in humans where the menstrual cycle is described as having a proliferative and a secretory phase of the uterus even though the human has follicular and luteal phase. The dominant ovarian structures during the follicular phase are ovarian follicles, most of which undergo growth followed by atresia and usually only one follicle will ovulate. In polytocous species such as rodents and swine, multiple follicles develop and ovulate. The luteal phase is characterized by the presence of the corpus luteum. In polytocous species such as the dog, cat, rabbit and pigs there are multiple corpora lutea ranging in number from 2–3 to 12–14 depending on the species.

Whereas the information in the above example is accurate, the presentation is full of extraneous detail that is not coherent with the main concept of the phases of the oestrous cycle. As a result, it is almost impossible for the listener, reader or viewer to identify and process the key information about the follicular and luteal phases. This is especially true for the beginning learner.

Extraneous information that is interesting, spectacular or even unbelievable, but not germane to the main concept to be learned, is called seductive detail. For example, if the objective is to teach the concept of how the degree of paramesonephric duct fusion results in various types of uterine morphology (simplex, bicornuate and duplex), then inserting the following seductive detail would detract from the main concept:

The word ‘hysterectomy’ means surgical removal of the uterus. The word is derived from a notion espoused by Plato (347–266 BC). He thought that the uterus was a multi-chambered organ that could wander about the body causing hysteria in the host woman. He thought that if a woman went too long without becoming pregnant her uterus would become indignant and would wander around the body causing extreme anxiety, hysteria, respiratory insufficiency and all sorts of diseases. The cure was removal of the uterus to remove the possibility of hysteria and disease. In spite of its ancient and erroneous origin, the term hysterectomy is still used today in the highest level of medical and scientific practice.

Most likely, students will be thinking about someone they know who had a hysterectomy and stop processing the concept of paramesonephric duct fusion.

PERSONALIZATION-information presented in a conversational style rather than a formal style results in improved learning

In our daily lives, we do not communicate in a formal way. Rather, we communicate in a personal way in almost all cases. Students learn more when the presentation style is in a conversational format than when it is more formalized (Kartal 2010; Mayer et al. 2004; Moreno and Mayer 2000a,b; Moreno and Mayer 2004). For example, utilizing phrases like ‘What we need to know is’, ‘It is important to understand’, ‘Now that we have described the pre-ovulatory LH surge, we want to describe how LH promotes a cascade of events resulting in ovulation’ can help increase student learning.

ANIMATION-dynamic processes that involve changes in anatomy/structure and hormonal secretion as it relates to time are more easily understood when animation is used

With advances in computer technology, animation has evolved from simple sequences of static images to more advanced 3D anatomical reconstructions coupled with continuous transitions of events. The benefit of animation when compared to static images is that animation can help the learner conceptualize continuous change over time and develop an appropriate mental framework for the concept (Gonzales 1996). Betrancourt (2005) proposes that the greatest benefit of animation is the ability to present changes that cannot be readily seen or easily visualized. Very difficult concepts such as follicular dynamics and the cycle of the seminiferous epithelium would benefit from 3D animation. Betrancourt (2005) proposes that an additional benefit of animation and computer simulation scenarios is where learners can explore the concept further and make predictions and changes using digital interactive features. Animated concepts can be adjusted easily into discreet sequences when static images are not beneficial (Hegarty et al. 2003). Thus, use of 3D animations has its most dramatic advantages in learning when it is used to explain very complex processes. For example, in reproductive science, explaining follicular dynamics using 3D animations is more effective than using a sequence of static images (Trevisan et al. 2010).

Research Findings – Multimedia in Reproductive Physiology

General characteristics of the multimedia programmes (‘Fast Track Learning’)

In 2006 and in 2008, Current Conceptions, Inc. received two Small Business Innovation Research (SBIR) contracts from the U.S. Department of Education. The overall purpose of this research was to develop multimedia prototypes describing various complex physiologic mechanisms in reproductive science and to evaluate learning outcomes among entry-level (Sophmore/Junior) undergraduate students in reproductive physiology. The research was conducted at six American land grant universities. Experiments were conducted before the topic of experimental content was delivered in the respective classes. The topics of the multimedia programmes were as follows: 'Mammalian Follicular Dynamics', 'The Physiology of Parturition', 'Assisted Reproductive Technology', 'The Menstrual Cycle and Oral Contraception' and 'Lactation and Breastfeeding'. These multimedia programmes were highly animated and utilized five different multimedia components. These were as follows: (i) step animations of 2D graphics (components of 2D graphics presented in sequence); (ii) 3D anatomical reconstructions of key anatomical components; (iii) 3D animations of critical action mechanisms such as cervical dilation, ovarian follicular development and ovulation, intracytoplasmic sperm injection (ICSI), milk ejection and milk transfer during nursing; (iv) each programme was narrated utilizing a script that was carefully synchronized with the presentation of images and events; and (v) script messaging was used to visually emphasize structures and events. The duration of the multimedia programmes ranged from 17 to 24 min. The instructional design of each programme was based on the principles described above. The following describes a series of four experiments designed to determine the efficacy of multimedia use for teaching reproductive science.

Each experiment incorporated random assignment of participants to treatment condition. Descriptive statistics and analysis of variance statistics (e.g. Student's t-test) were computed. Effect size estimates were also computed to provide an estimate of impact for any comparison that showed statistically significant differences. Effect sizes are computed by subtracting the mean of the control group from the mean of the treatment group and dividing by the pooled standard deviation. In this way, effect sizes are the measures of impact in standard deviation units. The formula is:

$$\text{Effect size} = \frac{\text{Mean}_{\text{treatment}} - \text{Mean}_{\text{control}}}{\text{Standard Deviation}_{\text{pooled}}}$$

A measure of prior learning in reproductive science was not obtained in these experiments. However, random assignment equates differences in the treatment and control groups. As a consequence, these differences are controlled for in the design.

Test reliability was also computed for each test. Reliability estimates are proportions and thus, range in value from 0.0 to 1.0. Test reliability is analogous to r^2 (i.e. correlation coefficient^2). For example, if the test reliability is 0.78, this means that 78% of the variation in test scores can be accounted for by student knowledge. In all experiments, tests were taken immediately after viewing the respective programmes. Therefore, test scores as a function of motivation or interest was minimized.

The following describes five experiments designed to determine the efficacy of multimedia use for teaching reproductive science.

Experiment I – Multimedia vs Classroom Lecture

The objective of the initial experiment was to compare learning outcomes from a classroom lecture with a digital multimedia presentation among university students. Both presentation methods described the physiology of mammalian follicular dynamics.

One half of the students in each of six university reproductive physiology courses viewed the multimedia programme, while the other half viewed a classroom lecture captured on video (Fig. 1). Immediately after viewing the respective programmes, students took a 20-item test to determine immediate recall (Fig. 1). Simultaneous viewing and test taking prevented cross-contamination among students.

The results of this experiment indicate that the multimedia programme was a highly effective instructional intervention for teaching follicular dynamics that resulted in increased student learning in approximately half the contact time. In spite of the encouraging outcomes, further research questions needed to be answered. These questions were as follows:

- Does type of animation (2D, 3D or both) impact student learning?
- Does multimedia impact student longer-term retention?
- Can results with university students be realized for educating a sample of the general public?

Experiment 2 – Impact of Animation Type on Learning

The objective of this experiment was to determine the impact of animation type on student learning. Students from five land grant universities were

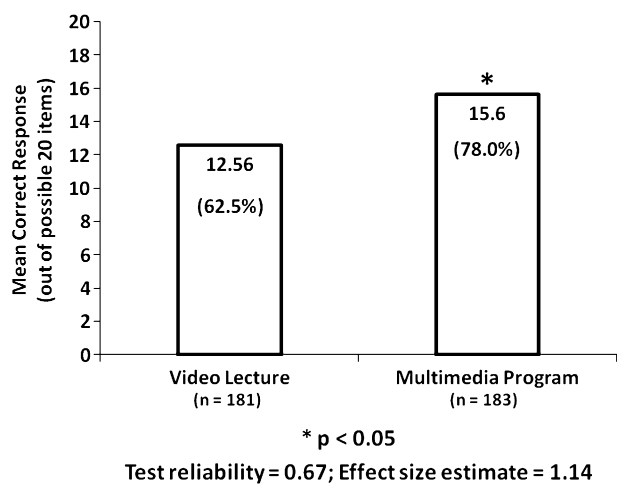

Fig. 1. Students viewing the multimedia programme significantly outperformed students viewing the same content from a lecture captured on video (modified from Trevisan et al. 2010)

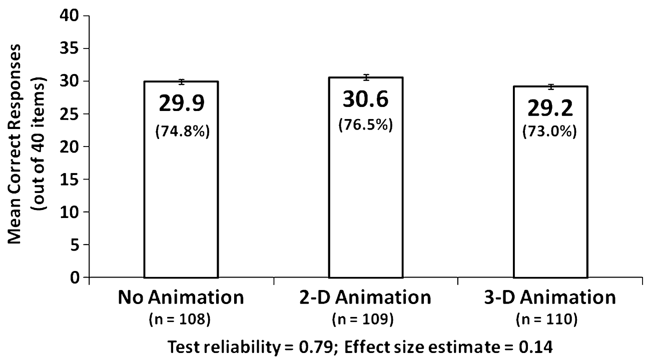

Fig. 2. Number of correct responses (% correct) to the 40-item multiple choice test administered immediately after students viewed a programme describing the menstrual cycle and oral contraception with varying degrees of animation

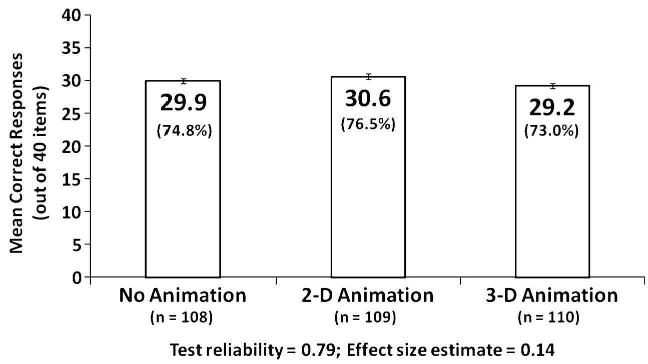

Fig. 3. Number of correct responses (% correct) on a 40-item multiple choice test administered after students viewed a multimedia programme describing the physiology of parturition. There was no difference ($p > 0.10$) in immediate recall of information between the concise (14 min) and the extraneous (24 min) learning conditions

randomly assigned to each of three treatments. These were (i) no animation, (ii) 2D animations and (iii) 2D and 3D animations. This multimedia programme described the physiology of the menstrual cycle and the mechanism of hormonal contraception. Immediately after viewing the respective presentations, students completed a 40-item multiple choice test. Type of animation did not influence student performance ($p > 0.10$). Mean test scores were high in all three learning conditions (74.8, 76.5 and 73.0, respectively; Fig. 2) indicating that all methods were effective at teaching about the physiology of the menstrual cycle and oral contraception.

Experiment 3 – Influence of Narration Length on Student Learning

The objective of this experiment was to determine whether extraneous information impacted learning. The topic for this presentation was the physiology of parturition. A total of 321 undergraduate students enroled in reproductive physiology course at five land grant universities students viewed either a concise (14 min) or a programme containing extraneous information in the narrative (24 min). Immediately after viewing the respective programmes, students completed a 40-item multiple choice test to assess their immediate recall of the information.

Narration length did not influence student learning ($p > 0.10$; Fig. 3). Mean exam scores were high for both groups (77.75% and 76.7%, respectively) indicating that student learning was consistent between a concise presentation (14 min) and a longer narrated presentation (24 min). We interpret that even though more information was presented in the long programme, it was not sufficiently extraneous to reduce learning outcomes.

The relatively high mean test scores in Experiments 2 and 3 suggest that multimedia presentations are effective at teaching complex concepts in reproductive physiology regardless of animation type or narration length. It should be emphasized that both multimedia presentations required significantly less time than that required by a traditional classroom lecture.

Experiment 4 – Impact of Multimedia on Long-Term Retention of Information

The objective of this experiment was to compare long-term retention of information about mammalian follicular dynamics from a lecture captured on video with a multimedia programme describing the identical concepts. Student participants (n = 46) were enrolled in reproductive physiology course at Washington State University. Students were randomly assigned to view either a multimedia programme or a lecture captured on video that describes ovarian follicular dynamics. Students completed a 25-item test immediately after the respective presentations, again 1 week later and again 1 month after viewing the respective presentations (Fig. 4). The test was the same for all three time periods, but the items were presented in scrambled item order with each successive test. Students who viewed the multimedia programme outperformed students in the video lecture on all three tests ($p = 0.02$).

Although not part of the original experimental design, the instructor lectured on follicular dynamics between the second and third tests. This unplanned infusion of information served as a 'knowledge booster' and both groups of students responded positively on the third tests. However, students who viewed the multimedia presentation retained more knowledge then did the students viewing the video lecture. As expected, performance on the second test was lower for both groups. This decrease in knowledge after 1 week is consistent with the studies of Roedinger and Karpicke (2006).

This preliminary study indicates that multimedia has promise for improving retention of knowledge particularly if 'knowledge boosters' are provided. As in the previous studies, students learned more in less time than that required by a traditional classroom lecture.

Experiment 5 – Effectiveness of Multimedia Presentation on Understanding the Physiology of Parturition by OB/GYN Patients

Based on the promising results seen in the previous experiments, we wondered whether complex concepts such as the physiology of parturition that was presented

Table 1. Patient demographics (N = 122)

Characteristic	Value
Age, mean (SD)	28.3 (6.7)
Gender (%)	
Female	100
Highest educational level achieved (%)	
Some high school	3.3
High school or GED	11.5
Some junior college or trade school	18.9
Degree from junior college or trade school	24.6
Some college or university	9.8
Degree from college or university	28.6
Graduate or professional school	3.3
No. previous children (%)	
0	54.9
1	25.4
2	11.5
3 or more	8.2

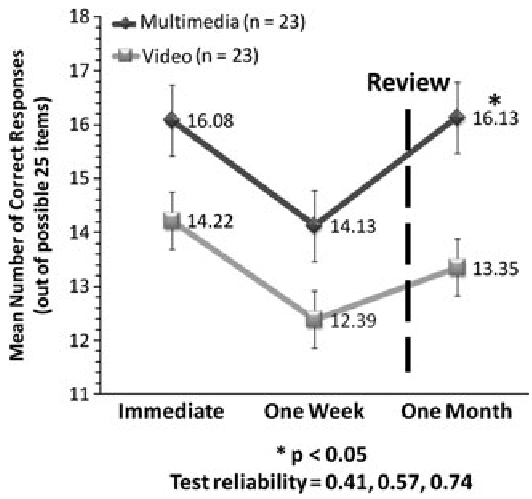

Fig. 4. The number of correct responses (% correct) to a 25-item test administered after the students viewed a multimedia programme describing mammalian follicular dynamics or viewed a lecture of the same content captured on video. Students completed the test immediately after viewing the respective programmes, again 1 week later and again 1 month later. The instructor lectured on the content approximately 2 weeks before the third test. Students who viewed the multimedia programme outperformed students who watched the video lecture at all three test periods

in multimedia form could be understood by the general public. To test this idea, we recruited OB/GYN patients to either view a multimedia presentation of an important topic in reproductive science (parturition) or read a pamphlet on the same material (the typical approach used to educate patients). In this experiment, the patients surveyed represented a broad range of educational achievement (Table 1).

The rationale for our hypothesis was that written educational materials provided for patient education are typically too complex for adult readers (Barkhordar et al. 2000; Doak et al. 1998; Maat and Lentz 2010; Meade et al. 1992; Murphy et al. 2000; Petterson et al. 1994). In addition, there is insufficient time for health care professionals to explain complex information during patient visits.

Patients (n = 122) from a large OB/GYN clinic in Spokane, WA, participated in the study. All participants were 18 years of age or older and were at various stages of pregnancy. Patients were randomly assigned to either read a booklet describing the physiology of parturition or view a multimedia programme describing the physiology of parturition. The booklet contained identical graphics and script as the multimedia programme. To avoid cross-contamination, each treatment was administered simultaneously in separate locations within the clinic.

After reading the booklet or viewing the multimedia programme, patients were given unlimited time to complete a 15-item multiple choice test. Patients viewing the multimedia programme (n = 65) outperformed patients reading the booklet ($p > 0.05$) on a 15-item multiple choice test (Fig. 5). The reliability estimate of the test was 0.75.

This study provides preliminary evidence that patients can understand complex physiologic concepts that are relevant to their health in a short period of time. Further, these results indicate that patients retained more knowledge when information is presented that utilizes both the auditory and visual channel. As multimedia programmes are designed according to established principles of cognitive theory, learning gains might be achieved beyond those obtained from written materials especially when information is provided to beginning learner.

Although not a direct comparison, university students viewing the same multimedia programme obtained a mean score of 88% on the same 15-item tests used in the current study. The patient multimedia group's mean score was 83%. This is an encouraging finding because it implies that complex information can be learned in a short period of time by individuals who have not had specialized training in this field of science. There may be significant opportunities to use this approach to educate members of the general public about important reproductive concepts such as contraception, the physiology of the menstrual cycle, assisted reproductive technologies and other health-related reproductive functions.

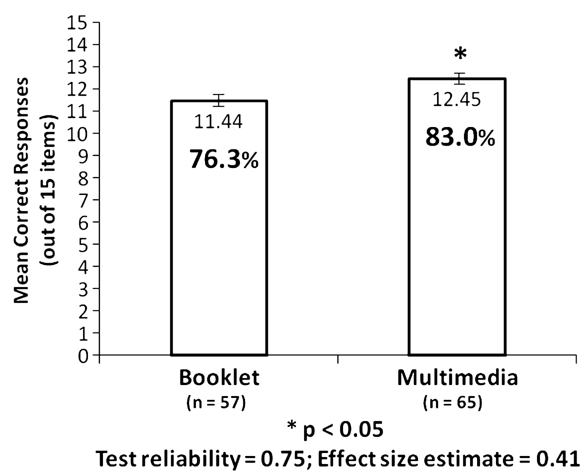

Fig. 5. The number of correct responses (% correct) to a 15-item multiple choice test. Patients either read a booklet or viewed a multimedia programme describing the physiology of parturition. Patients viewing the multimedia programme outperformed ($p < 0.05$) patients reading the booklet

This might be especially true when learners are presented topics that are relevant to a specific health condition or need. For example, one might assume that expectant mothers would be motivated to learn about parturition.

Conclusions

These experiments have the following overall implications:

- Students viewing multimedia programmes that employed documented principles of instructional design learned as much or more in significantly less time than that required by a traditional classroom lecture.
- Retention of knowledge appears to be better with multimedia when compared to a lecture presentation. However, more data are needed to confirm these preliminary findings.
- Members of the general public, (as judged by patients in Ob/GYN clinic) who do not have specific training in reproductive physiology can understand complex concepts, if documented principles of instructional design are followed.

In summary, exploiting the power of multimedia in teaching reproductive science, especially when coupled with online delivery, may enable a much wider audience (ranging from the general public to university students) to be reached than heretofore ever imagined with traditional classroom delivery techniques.

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Conflicts of interest

None of the authors have any conflicts of interest to declare.

Author contributions

Drs. Senger and Oki developed the instructional design for all multimedia programs; Drs. Senger, Trevisan and McLean were responsible for the experimental design of Experiments 1, 2 and 3; Dr. Trevisan analyzed data for Experiments 1, 2 and 3. Drs. Oki and McLean were responsible for the experimental design of Experiments 4 and 5. Dr. Oki analyzed data for Experiments 4 and 5. Dr. McLean served as the Ph.D. advisor for Dr. Oki.

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