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Saying the wrong thing: improving learning with multimedia by including misconceptions

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Abstract In this study, 364 first-year physics students were randomly assigned to one of four online multimedia treatments on Newton's First and Second Laws of Motion: (1) the 'Exposition', a concise lecture-style presentation; (2) the 'Extended Exposition', the Exposition with additional interesting information; (3) the 'Refutation', the Exposition with common misconceptions explicitly stated and refuted; or (4) the 'Dialogue', a student–tutor discussion of the same material as in the Refutation. Students were tested using questions from mechanics conceptual inventories before and after watching the multimedia treatments. Results show the Refutation and Dialogue produced the greatest learning gains, with effect sizes of 0.79 and 0.83, respectively, compared with the Exposition. Students with low prior knowledge benefited most, however high prior knowledge learners were not disadvantaged by the misconception-based approach. The findings suggest that online multimedia can be greatly improved, promoting conceptual change in students with all levels of experience, by including a discussion of misconceptions.

Keywords cognitive load theory, conceptual change, misconceptions, multimedia learning, physics education research, vicarious learning.

Introduction

With students no longer perceived as passive recipients of knowledge, the role of misconceptions as central obstacles to effective science education has been well established (Chi *et al*. 1994; Vosniadou 1994; Duit & Treagust 2003; diSessa 2006). Over the past 30 years, physics education researchers have documented misconceptions, attempted to overcome them, and evaluated interventions with conceptual inventories (Hake 1998; Crouch & Mazur 2001). Successful teaching practices have been implemented in a small number of physics classrooms internationally (Redish & Steinberg 1999; McDermott & Shaffer 2001). These often involve strategically planned tutorials, concept checks in lecture classes and increased opportunities for student discussion. However, limited research has been conducted on how resources like linear multimedia can be altered to promote conceptual change.

Multimedia research has investigated student learning of scientific topics like the formation of lightning (Mayer *et al*. 1996) and deep-sea waves (Mayer & Jackson 2005), but the issue of misconceptions has rarely been addressed. Studies have also typically been conducted in controlled laboratory environments, with learners who have little or no prior knowledge about the subject matter nor experience in the ways of knowing, learning and thinking in the domain.

Research on simulations and other interactive multimedia is addressing the issue of conceptual change. On the topic of electric circuits, Ronen and Eliahu (2000)

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found that simulation feedback helped students recognize and change their misconceptions. A further study confirmed that over the course of a semester, students who used both real and virtual experiments developed a stronger conceptual understanding than those who used real experiments alone (Zacharia 2007). However, an important finding in interactive settings is that learners often require more scaffolding to focus on conceptual issues (Lowe 2004; van Joolingen *et al*. 2007). With a projectile motion simulation, Yeo *et al*. (2004) found that students interacted superficially and retained their intuitive conceptions. Only after researcher intervention did they focus on the salient conceptual issues in the program. Linear multimedia could serve this scaffolding function, emphasizing important aspects of a simulation and guiding learner manipulations. If it is possible to promote conceptual change effectively with multimedia, it could be used on its own, as part of online collaborative exercises, or with simulations. Linear multimedia is one of the most common forms of multimedia online because it is inexpensive and straightforward to create. With the proliferation of online lectures, and websites like http://YouTube.com registering 100 million downloads per day, video has become a central communication medium facilitated by computers.

How then should misconceptions be addressed in non-interactive multimedia? In this study we sought to investigate the following questions in a real learning context:

- Does explicit discussion of misconceptions in multimedia lead to enhanced learning compared with concise explanations?
- Does the level of students' scientifically accurate prior knowledge influence the degree to which different teaching methods are effective?

These questions were investigated by comparing four instructional multimedia treatments. The Exposition, Extended Exposition, Refutation and Dialogue were designed to resemble learners' experiences in different physics instructional environments. The Exposition provided a concise summary of the correct physics involved in Newton's First and Second Laws. The Extended Exposition contained additional interesting information related to the topic, which was not examined in the post-test. In the Refutation treatment, a single speaker mentioned common misconceptions while describing Newton's Laws and explained how the misconceptions were inadequate. In the Dialogue treatment, a student raised the same misconceptions and then engaged in discussion with a tutor to resolve inconsistent ideas. Screen shots from the multimedia are shown in Fig 1.

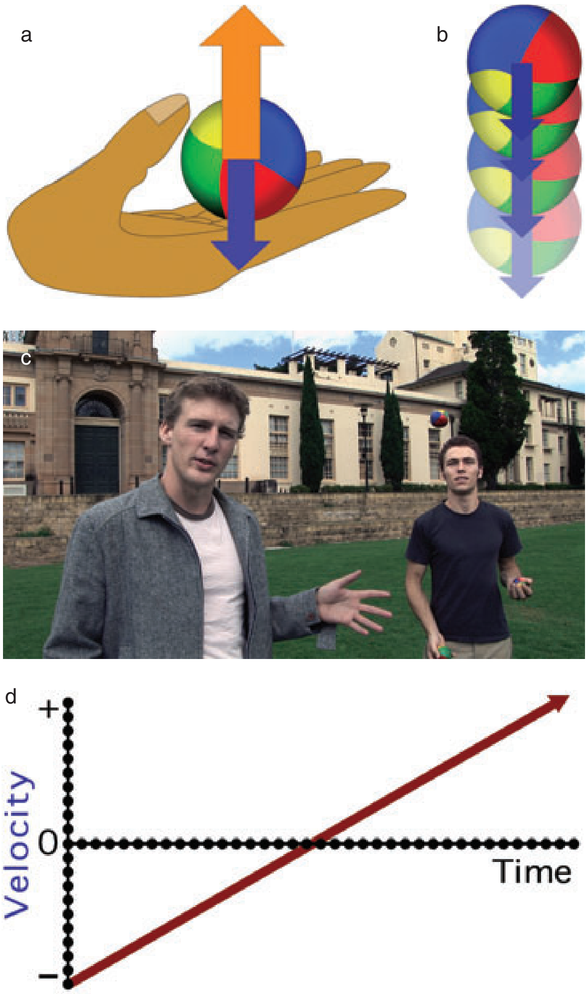

Fig 1 All multimedia treatments contained (a) diagrams, (b) animations, (c) live action demonstrations and (d) graphs.

Misconceptions added to multimedia treatments have the potential to help or hinder learning. They may impose an extraneous cognitive load on the learner, inhibiting him or her from building a correct, coherent mental model. Or they may help by highlighting possible differences between scientific theories and a learner's prior knowledge, increasing germane cognitive load. These considerations are outlined in detail below.

Why should misconception treatments be superior?

Although learning is often thought of as a process of accretion, as mentioned in the *Introduction*, in introductory science education reorganization of concepts seems to be the essential mode of learning. Posner *et al.* (1982) proposed that dissatisfaction with existing mental models is the first step towards conceptual change. This has been supported by a number of experiments in which different methods have been used to create cognitive conflict (Guzzetti *et al.* 1993; Limon 2001). Although there is debate over which methods are most effective, many cognitive conflict tactics used in classrooms have demonstrated improved performance compared with traditional instructional approaches (Duit & Treagust 2003; Vosniadou & Verschaffel 2004). Therefore, misconception treatments should activate students' prior knowledge and help them recognize any disparity between their ideas and correct scientific theories.

In the classroom, teaching interventions developed to overcome misconceptions almost universally use interactive teaching and learning methods. Interactive engagement lectures aim to engage students in 'heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors' (Hake 1998, p. 65). Peer Instruction (Mazur 1997; Crouch & Mazur 2001) and Interactive Lecture Demonstrations (Thornton & Sokoloff 1998) involve students in discussions about their ideas in small groups before reporting back to the lecturer. Workshop Tutorials (Sharma *et al.* 2005) and Tutorials in Introductory Physics (McDermott & Shaffer 2001) promote discussion outside of lectures in small groups as students work through physics problems under the supervision of tutors.

All of these methods have demonstrated improved performance, often measured with the Force Concept Inventory (Hestenes *et al.* 1992; Halloun & Hestenes 1995; Mazur 1997) or the Force and Motion Conceptual Evaluation (Thornton & Sokoloff 1998). Interactive engagement lectures, for example, showed almost two standard deviations of improvement over traditional teaching methods in a survey of 62 courses (Hake 1998). The challenge of addressing and changing student misconceptions has been approached in small classrooms, tutorials, and in lectures through activities and discussion. It has little been investigated, however, whether or how non-interactive resources with which students learn can facilitate conceptual change.

The Dialogue treatment in this study was inspired by the emphasis on student discussion in successful reform teaching methods. Studies of 'vicarious learning' in which students learn by observing a recorded student–tutor interaction have shown that this technique can be as effective as didactic teaching (Cox *et al.* 1999; for theoretical background see McKendree *et al.* 1998; Lee *et al.* 1999). These studies did not consider, however, the role vicarious learning could play in confronting and changing misconceptions.

In non-interactive media, studies have been carried out on so-called 'refutation texts', in which misconceptions are discussed and rejected (for a review, see Guzzetti *et al.* 1993). Although some conflicting findings were reported, in general text that attempted to create cognitive conflict resulted in greater learning gains than non-refutational text. A study of elementary science students found that a refutational text passage on energy, which addressed two prominent preconceptions, was much more effective as an adjunct to standard class teaching than an expository text (Diakidoy *et al.* 2003). One extensive qualitative study (Guzzetti *et al.* 1997) found that refutation texts do induce cognitive conflict and over a period of months can help students develop correct scientific understandings. In some cases, however, students found support for their alternative conceptions in refutation texts when the refutation was not direct enough or when students lacked necessary reading strategies.

Why should concise treatments be superior?

In research on multimedia, the finding that succinct instruction leads to more learning has been confirmed in a variety of empirical contexts (Chandler & Sweller 1991; Mayer 2001, 2003, 2005). Instructional messages that contain redundant information sources inhibit learning in what is called the *redundancy effect* (Sweller *et al.* 1998). A related recommendation – that all non-essential information be removed from instructional messages is sometimes called the *coherence principle*:

> Adding extraneous words or pictures to a multimedia message can interfere with . . . cognitive processes . . . by encouraging learners to pay attention to words or images

> that are not relevant, by disrupting how learners organize words or pictures into a causal chain, and by priming inappropriate schemas to be used to assimilate the incoming words and pictures. (Mayer 2003, p. 133)

In short, multimedia messages that include non-essential material often distract learners from the cognitive processes required for learning. At the heart of the redundancy effect and the coherence principle is cognitive load theory (Sweller 1994; Sweller *et al*. 1998). Cognitive load theory is a theory of instructional design that is based on the limited capacity of humans to process novel information. It asserts that instructional design must be primarily concerned with allocating cognitive resources to those activities which lead to desired changes in long-term memory. Thus far, researchers in this area have focused on how this may best be achieved. Cognitive load can be broken down into three types: intrinsic, extraneous and germane. Intrinsic cognitive load is a property of the material to be learned and therefore cannot be altered by instructional design. Extraneous cognitive load, on the other hand, reflects the additional cognitive effort required to learn from poorly designed instruction. Germane cognitive load refers to the cognitive effort involved in schema formation and is therefore most important for learning. The goal of instructional design is to minimize extraneous cognitive load and maximize germane load.

From the perspective of cognitive load theory, there is a risk that adding misconceptions to a concise scientific presentation may interfere with learning. When viewing a misconception treatment, learners must select from a greater number of words and pictures to form coherent mental models. They must also pay attention for a longer duration to see the same amount of correct scientific information. Furthermore, in both of the misconception-based treatments, force diagrams and animations were shown to illustrate multiple misconceptions. In the Dialogue, misconceptions were presented as the genuine beliefs of one of the dialogue participants without cautioning students that not all of the information in the treatment was correct. Resolutions were reached later, through discussions between the student and tutor.

In addition, not all students have the same misconceptions, so a discussion that might be useful for some students would likely be irrelevant for others. Multimedia researchers have found that some instructional guidance that benefits novices can hinder learners experienced in the area, in what is called the *expertise reversal effect* (Kalyuga *et al*. 1998, 2003). Therefore, one might expect a discussion of misconceptions to be beneficial for novice learners but detrimental for those more experienced.

Multimedia containing misconceptions is significantly different from refutation text because multimedia is transient in time. While reading refutation texts, learners can easily refer back and forth between misconceptions and correct scientific ideas. In contrast, viewers of misconception-based multimedia must develop their understandings as the multimedia progresses. This increases the likelihood that the added material may misdirect or overload learners.

Finally, some researchers may be sceptical of non-interactive media promoting conceptual change in any sense. Often behavioural activity is believed necessary to inspire cognitive activity, making it essential for conceptual change. 'Learning is an effortful and mindful process and students should be encouraged to construct their own knowledge and skills through active processing, rather than being passive listeners.' (Vosniadou *et al*. 2001, p. 382) This statement begs the question: can one make learners active listeners, and if so, how?

Method

Participants and design

The participants were 678 first-year physics students at the University of Sydney from three physics streams: Fundamentals, for students with little prior formal instruction in physics; Regular, for students with senior high school physics backgrounds; and Advanced, for students who excelled in senior high school subjects and physics in particular. As part of their first assignment, students were asked to access a website to receive a participation mark. At the website they completed a pre-test, received a randomly assigned multimedia treatment and completed a post-test. Participants' answers and the times at which they were submitted were written to a MYSQL database. This allowed for determination of the time spent on the pre- and post-tests and the time spent watching the multimedia treatment.

As the experiment was conducted in an authentic setting and participants were allowed to withdraw at any time, the data required filtering prior to analysis. Participants were removed from the data set for failing to complete the post-test ($n = 116$), watching more than one multimedia treatment ($n = 75$), not watching the multimedia in its entirety ($n = 30$), spending less than 4 min completing the pre- or post-test ($n = 57$), failing to answer all questions ($n = 6$), or scoring higher than 95% on the pre-test ($n = 30$). Students were able to watch more than one multimedia treatment by using the back button in their browser or by manually changing the website URL.

Using a website to administer the materials for this study had several advantages. It allowed for large numbers of students from authentic lecture courses in physics to be surveyed. The times of submission for each question were easily recorded and participants were able to complete the study in their own time at their own pace. Assignments to video treatments were completely randomized using a Hypertext Preprocessor script. Some drawbacks of the website set-up included the high bandwidth required to view the multimedia treatments over the Internet. Participants either required broadband at home or had to complete the study from an on-campus access lab.

Many variables were out of the researchers' control. Participants accessed the experiment wherever and whenever they liked. They may have used resources or consulted with peers when answering the pre- or post-test questions. Although the time between the start and end of the multimedia was calculated, an appropriate length of time was no guarantee that a student actually watched the treatment. These were features of the methodology; the ability of students to participate as they saw fit ensured the results could be generalized to authentic learning environments.

Materials and apparatus

The pre- and post-tests consisted of the same 26 multiple choice questions. Twenty-two questions were from the Force and Motion Conceptual Evaluation (Thornton & Sokoloff 1998). Three questions were from the Force Concept Inventory (Hestenes *et al.* 1992; Mazur 1997) and one question was written by the researchers. Reliability estimates of both tests have been made (MacIsaac *et al.* 2002; Ramlo 2002) with Cronbach's α ranging from 0.85 to 0.94. Previous experiments with these tests (see Henderson 2002) have shown that no measurable learning occurs simply by taking the test, eliminating the need for a non-intervention control group. The test involved a mixture of retention and transfer questions. The answers to 12 questions were directly stated in each treatment, while the other 14 required application of learned principles to new situations. Each question was worth one mark.

Multimedia treatments

Newton's First and Second Laws are fundamental to virtually all introductory physics courses, but they are notoriously difficult to learn because they contradict common sense ideas about motion (McClosky 1983). As the subject matter is common and so widely misunderstood, extensive research has been carried out to document common student misconceptions (McDermott 1991; Mayer 2004). Hence, Newton's First and Second Laws were selected as the focus of the multimedia treatments in this study, with design informed by misconception research (Trowbridge & McDermott 1980, 1981; Clement 1982; McClosky 1983; Halloun & Hestenes 1985; diSessa 1996). The Refutation and Dialogue included the most common misconceptions involving Newton's First and Second Laws, which are summarized below:

- believing an unbalanced force is required to keep an object moving with constant velocity;
- confusing velocity and acceleration;
- confusing position and velocity;
- confusing momentum with force; and
- believing that an increasing force is required to achieve constant acceleration.

To explicate the physics concepts, all of the multimedia treatments examined three examples: a book pushed across a table at constant speed, a juggling ball thrown upwards and caught, and a toy car rolling up and down a ramp. The treatments ranged in length from 7 to 11.5 min. The scripts were written with reference to several textbooks (Hewitt 1997; Young & Freedman 2000; Halliday *et al.* 2003) and were critiqued by a panel of three physics educators, each with over 30 years of experience. The scripts were iteratively compared and contrasted throughout the writing process to ensure all treatments contained exactly the same accurate physics information. All treatments included diagrams, animations and live action demonstrations and were created in line with multimedia design principles (Mayer 2005). Specifically, words

Table 1. Summary of multimedia treatment attributes.

Treatment	Exposition	Extended Exposition	Refutation	Dialogue
Number of speakers	1	1	1	2
Length (minutes:seconds)	7:02	11:22	9:33	11:22
Addresses misconceptions	No	No	Yes	Yes

were presented as narration rather than on-screen text; related concepts were presented contiguously in time and space; and extraneous sounds and images were avoided as much as possible. After the treatments were completed, they were again critiqued by physics educators to ensure there existed no inconsistencies in physics content.

The Exposition was designed to be very similar to a concise presentation a well-prepared lecturer might make on the topic of Newton's Laws. It included graphs, force diagrams, animations and live action demonstrations, along with 'talking head' narration. The Extended Exposition and the Refutation consisted of the Exposition plus additional material. Interesting information beyond the assessed learning outcomes was added in the Extended Exposition to make it equal in length with the Dialogue. Thus it served as a control for the time students spent thinking about the physics and, in conjunction with the Exposition, it allowed for an investigation of the applicability of the coherence principle (Mayer 2001, 2003) in an authentic physics setting. Common misconceptions were explicitly raised and refuted in the Refutation to investigate this method of recognizing anomaly between prior knowledge and scientific theory. Previous studies on refutation texts were used to inform the writing of this script (Guzzetti *et al*. 1997; Diakidoy *et al*. 2003).

The Dialogue was entirely different in structure to the other three treatments, utilizing a simulated discussion between an inquisitive student and a tutor. Over the course of the discussion, the student's misconceptions, the same as those in the Refutation, were revealed and corrected through Socratic dialogue (Hake 1992). Parts of the dialogue script were inspired by transcripts of a student's interviews on Newton's Laws (diSessa 1996). Where possible the same phrases as in the Expositions were used in the Dialogue. A summary of the similarities and differences between the four treatments is shown in Table 1. Sample corresponding script segments are included in Appendix I.

Procedure

All students taking first year physics at the University of Sydney were asked to access a website for one mark towards their first assignment. A consent form on the opening page informed students that

- the study would take between 30 and 45 min to complete;
- the study should be completed individually without referring to textbooks or online resources;
- performance on the pre- and post-tests would be kept confidential; and
- participation in the study was voluntary and that they could withdraw at any time with no penalty.

Between pre- and post-tests, participants were randomly assigned to one of the four multimedia treatments. After completing the post-test, each student received their mark on that test along with helpful suggestions about resources they could use to improve their understanding. Students who scored below 40% were not told their exact mark, and additional aids were recommended. A record of all students who accessed the website, regardless of whether they completed the study, was sent to the course coordinator who allocated participation marks.

Results and analysis

The scores on the pre- and post-tests were not normally distributed. This was due to the large number of students with widely varied abilities. Non-parametric tests revealed no significant differences among the pre-test results across the four treatment groups; however, post-test results were significantly different (Kruskal–Wallis $\chi^2 = 8.625$, $P = 0.035$, Median Test $\chi^2 = 9.565$, $P = 0.023$). Gender composition was not significantly different across the four treatment groups, nor was the time spent completing the pre- or post-tests.

Table 2. Gain statistics for the four multimedia treatments.

Treatment	Sample size (*n*)	Median pre-test	Median post-test	Mean gain	Standard deviation
Dialogue	92	8.5	16	4.77*	4.59
Refutation	86	7.5	14	4.41*	4.01
Extended Exposition	95	8.0	12	2.41	3.72
Exposition	91	8.0	9	1.77	2.65

*Dialogue and Refutation mean gains were significantly greater than the Exposition and Extended Exposition at $P < 0.01$.

Differences between treatments

To determine the relative effectiveness of the multimedia treatments, a gain score for each student was computed by subtracting their pre-test mark from their post-test mark (each of which had a maximum of 26 marks). Gain was normally distributed for each treatment group. The sample size, median pre- and post-test scores, mean gain and unbiased standard deviation, are shown in Table 2.

Using a one-way ANOVA the gains of the treatments were compared yielding a significant difference between treatments ($F(3, 361) = 13.625$, $P < 0.00001$). The Games-Howell *post hoc* procedure, which does not assume equal variance, showed the gains for students who watched the Dialogue or the Refutation were significantly greater than those who received the Exposition ($P < 0.0001$) or Extended Exposition treatments ($P = 0.001$ for the Dialogue, $P = 0.004$ for the Refutation). The effect size for these differences in comparison to the Exposition was 0.83 for the Dialogue and 0.79 for the Refutation.

Gain dependence on prior knowledge

Students from the three physics streams had different levels of prior physics instruction, allowing for an investigation of the dependence of gain on prior knowledge. It was expected that the Fundamentals students, with the least prior physics instruction, would hold the most misconceptions and therefore benefit most from misconception-based instruction. Regular students, having completed Newtonian mechanics in high school, represented a mixture of prior knowledge. It was therefore unclear which treatment would be most advantageous for them. Advanced students, with significant accurate prior knowledge, were expected to achieve greatest learning gains with the concise treatment. The mean gains for each treatment, separated by physics stream, are shown in Fig 2.

Fundamentals students who watched the Dialogue or Refutation had significantly greater gains than those who watched the Exposition ($F(3, 109) = 6.609$, $P < 0.001$). Similarly, in the Regular stream the Dialogue and Refutation students achieved significantly greater gains than Exposition students ($F(3, 163) = 7.262$, $P = 0.0001$). Students from the Advanced stream did not show significantly different gains between treatments, although the trends in means observed are similar to those above ($F(3, 83) = 2.069$, $P = 0.111$). The lack of significant difference might be due to the small sample size in this stream and a possible ceiling effect on the post-test. The median score for the Advanced stream on the post-test was 85%, compared with 23% and 54% for the Fundamentals and Regular streams, respectively.

Discussion

Theoretical implications

Using questions from standard mechanics conceptual inventories, students from three lecture courses in first year physics were tested before and after watching a short multimedia treatment about Newton's First and Second Laws. Results show that overall students achieved greater gains by watching a treatment that addressed misconceptions than one which presented only correct scientific information. This suggests that the increased cognitive load incurred with misconception-based treatments was germane rather than extraneous, on the average, for students with all levels of prior knowledge.

The results of this study are consistent with the findings of conceptual change research that suggest cognitive conflict is essential to conceptual change (Guzzetti *et al*. 1993). As both Refutation and Dialogue

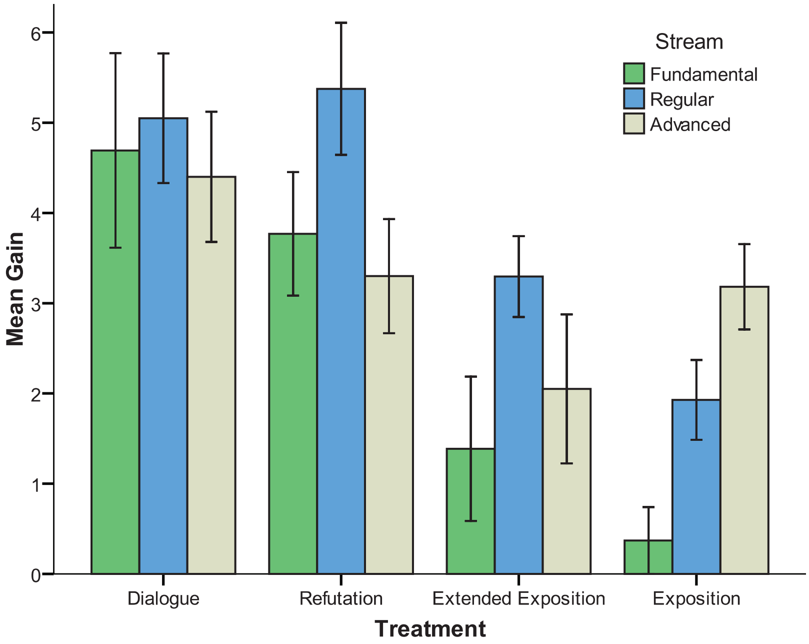

Fig 2 Mean gains (pre-test – post-test) for the four multimedia treatments after separating by physics stream. Error bars: ±1 standard error.

treatments produced similar effect sizes, it seems that both methods of recognizing the anomaly between prior knowledge and scientific theory are equally effective in non-interactive multimedia. Follow-up interviews will investigate student perceptions of Refutation and Dialogue methods.

The findings highlight the need to consider what constitutes extraneous information in the context of cognitive load theory. In the standard practice of teaching physics, misconceptions are not considered essential teaching material. They are addressed when the need arises, in response to student questions or answers on assessment. Even then, feedback may only address the specific problem without clearly explaining a misconception in its entirety. Almost all textbooks, including those used by the students in this study, do not include discussions of misconceptions. However, the addition of incorrect information to form the Dialogue and Refutation treatments was essential for students to engage in germane processing; it did not impose an onerous extraneous load on students.

One might expect the discussion of misconceptions to be particularly irrelevant for the Advanced students, given their experience with Newtonian mechanics and excellent performance on high school assessment tasks. However, no analogue of the expertise reversal effect was found. Advanced students in the misconception treatments achieved non-significantly greater gains than their peers in the concise treatment. Although studies have shown misconceptions to be quite persistent, it is unlikely that Advanced students held misconceptions to anywhere near the same degree as Fundamentals students. The explicit discussion of misconceptions seems to be an effective instructional strategy whether students actually hold the misconceptions or not.

With respect to the Exposition and the Extended Exposition, the effects of the coherence principle were not observable using the multiple-choice pre- and post-tests in this setting. This result suggests that interesting but irrelevant information might encourage students to pay attention to online multimedia when they are watching it in their own time. Alternatively, the multiple-choice tests may not have been sensitive to the differences in learning between the two treatments. Replications of laboratory studies that investigated the impact of additional interesting information conducted in authentic learning environments could shed light on the issue. This highlights another possible area in which seemingly extraneous information in a laboratory setting might yield a germane cognitive load in authentic learning contexts. In a laboratory, a learner's intrinsic motivation to engage with instructional material is likely less important than in an unstructured environment where, without researcher supervision, he may freely decide how to direct his attention. A previous study has found that some well-established multimedia principles fail to generalize easily to authentic settings (Tabbers *et al*. 2004). Further research is required to determine whether the coherence principle holds in authentic settings.

In future studies, an attempt to measure the cognitive load of students may help to understand and interpret results. In a setting like that of the present experiment, this would most likely be achieved through self-reported rating scales, however, other techniques could be used in a laboratory setting (Paas *et al*. 2003).

This study helps to understand an 'active ingredient' in the reform methods developed to achieve conceptual change through lecture instruction (e.g. Hake 1998). Physics education research has been criticized for comparing instructional strategies where several variables have been altered simultaneously (Guzzetti *et al*. 1993). Reform teaching methods include various combinations of hands-on activities, discussions with peers, increased instructor feedback, demonstrations involving learning cycles, written worksheets and classroom communication systems, leaving in doubt the essential factors that enhance learning. The results of this study suggest that part of the benefit of interactive lecture classes and tutorials is likely derived from students observing discussions between other students and tutors in which misconceptions are addressed. Discussions of this sort are quite rare in traditional lecture classrooms (Graesser & Person 1994; Muller 2005).

Practical implications

The results of this study suggest that, unlike other non-essential information, discussing misconceptions does not interfere with learning when added to multimedia. When designing multimedia for science education areas, developers should therefore address common misconceptions explicitly in their explanations of appropriate topics. Although their inclusion in multimedia results in longer interventions with more words and diagrams, they serve a useful pedagogic purpose, aiding learners to consider scientific conceptions in light of their prior knowledge.

In addition, although interactive methods in lectures have demonstrated substantial gains in conceptual understanding over traditional methods, this study suggests that raising misconceptions in traditional-style lectures should increase student conceptual understanding. This is an important result for teachers who find it difficult to implement interactive methods owing to restrictions on time, money and technology, often coupled with large class sizes. Multimedia interventions that address misconceptions, like those investigated in this study, could be used in lectures to highlight key conceptual difficulties. Additionally, they could be used to provide conceptual scaffolding for interactive multimedia.

Despite the verified advantages of reform teaching methods and refutation texts, uptake of these strategies has been quite limited. The practical drawbacks of refutation texts are clear; they require more research and writing to produce and they result in heavier, bulkier books. Challenges of implementation for reform teaching methods are similar. They require substantial investments of time and money, specialized training, and often result in a decrease in the number of learning outcomes that can be achieved in the same number of contact hours. The Internet offers a new means of circumventing some of these difficulties. Multimedia is almost as readily available as text and is not cumbersome to carry like a textbook. Adding misconceptions only increases the duration of instruction, which as demonstrated in this study can dramatically increase the learning gains in an authentic setting.

The success of conceptual change interventions is often heavily dependent on the expertise of the teacher (Limon 2001). Addressing misconceptions through multimedia rather than teacher-led discussion reduces the burden on teachers and increases the likelihood of success. Teachers are often hesitant about conducting conceptually challenging discussions owing to concerns about time constraints or their own mastery of the subject (Weaver 1998).

It is important to note that although misconception-based multimedia on average resulted in greater learning gains, it is not a standalone solution to conceptual difficulties. The process of moving from alternative ideas to a coherent scientific view is complex and it remains only partially understood. Undoubtedly, discussions among students and between students and teachers are important for developing accurate conceptual understandings. Multimedia that addresses misconceptions is simply one resource that may help students along the path to scientific reasoning. Furthermore, the misconception-based techniques presented in this study may be useful adjuncts to simulations or online discussions, to help focus learner attention on salient conceptual issues.

Previous studies have shown that reducing extraneous cognitive load is vital for learning science with multimedia. Even relevant equations have been shown to interfere with the development of conceptual understandings. However, the extra cognitive load involved in raising and refuting common misconceptions seems justified by the increased gain achieved by students who received misconception treatments.

Appendix I Comparison of juggling script segments

Exposition	Extended exposition[1]	Refutation[1]	Dialogue[1]
While the ball is in the air (we will ignore air friction because it is so small) only one force acts on the ball throughout its flight. This is the force of gravity which is constant and downwards, accelerating the ball in the downward direction. After being thrown up, a ball travels slower and slower upwards, stopping momentarily before speeding up in the downward direction. Then it meets with the juggler's hand again and the process repeats	If you are learning to juggle it might be nice to have the balls fall a bit slower to give you more time to coordinate your efforts catching and throwing the balls. Unfortunately if you use lighter balls, they won't fall any slower than heavy ones. Even though the force of gravity on them is less, it takes proportionately less force to accelerate them by Newton's second law, so there is no net effect and the balls accelerate at the same rate whether they are heavy or light. The only advantage of using light balls is that you won't expend as much energy throwing them into the air. Something you might try to make learning to juggle easier would be juggling tissues or scarves. These items have significant air resistance so they don't accelerate downwards at the same rate as balls. Most beginners start out this way and work up to more aerodynamic and even dangerous objects later.	A misconception is that as the ball travels upwards, there is an upward force from the juggler's hand that stays with the ball even after the ball has lost contact with the juggler's hand – a force in the ball to keep it moving. This force gradually dies away until it balances gravitational force at the peak. Then gravity takes over and pulls the ball downward. However, there is no upward force on the ball after it has left the juggler's hand and gravity is acting all the time. In this misconception we are simply confusing velocity with force	Tutor: Can you tell me what happens when a single ball goes around once? Student: Well the juggler's hand gives the ball a force that drives it upward against gravity – but as it goes up that force dies away, right? So at the top then, it perfectly balances gravity – then gravity wins and the ball falls downward. Tutor: Hmm . . . you said that the force from his hand and gravity are equal at the top. Student: Yeah. Tutor: Then why doesn't the ball keep doing what it's doing? Student: I don't know. Maybe air resistance – no. I mean they're only balanced for a split second – so then gravity wins – I don't know, I must be missing something. Tutor: Does it make sense that the juggler's hand can put a force on the ball after it leaves his hand? Student: No . . . not really. But the ball's still going up, isn't it? Doesn't that mean there's a force?

[1] Only extra material is presented.

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References

Chandler P. & Sweller J. (1991) Cognitive load theory and the format of instruction. *Cognition and Instruction* **8**, 293–332.

Chi M.T.H., Slotta J.D. & De Leeuw N. (1994) From things to processes: a theory of conceptual change for learning science concepts. *Learning and Instruction* **4**, 27–43.

Clement J. (1982) Students' preconceptions in introductory mechanics. *American Journal of Physics* **50**, 66.

Cox R., McKendree J., Tobin R., Lee J. & Mayes T. (1999) Vicarious learning from dialogue and discourse. *Instructional Science* **27**, 431–458.

Crouch C.H. & Mazur E. (2001) Peer instruction: ten years of experience and results. *American Journal of Physics* **69**, 970–977.

Diakidoy I.N., Kendeou P. & Ioannides C. (2003) Reading about energy: the effects of text structure in science learning and conceptual change. *Contemporary Educational Psychology* **28**, 335–356.

Duit R. & Treagust D.F. (2003) Conceptual change: a powerful framework for improving science teaching and learning. *International Journal of Science Education* **25**, 671–688.

Graesser A.C. & Person N.K. (1994) Question asking during tutoring. *American Educational Research Journal* **31**, 104–137.

Guzzetti B.J., Snyder T.E., Glass G.V. & Gamas W.S. (1993) Promoting conceptual change in science: a comparative meta-analysis of instructional interventions from reading education and science education. *Reading Research Quarterly* **28**, 116–159.

Guzzetti B.J., Williams W.O., Skeels S.A. & Wu S.M. (1997) Influence of text structure on learning counterintuitive physics concepts. *Journal of Research in Science Teaching* **34**, 701–719.

Hake R.R. (1992) Socratic pedagogy in the introductory physics laboratory. *Physics Teacher* **30**, 546–552.

Hake R.R. (1998) Interactive-engagement vs. traditional methods: a six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics* **66**, 64–74.

Halliday D., Resnick R. & Walker J. (2003) *Fundamentalss of Physics*, 6th edition. Wiley, New York.

Halloun I.A. & Hestenes D. (1985) The initial knowledge state of college physics students. *American Journal of Physics* **53**, 1043–1055.

Halloun I.A. & Hestenes D. (1995) Interpreting the Force Concept Inventory. *Physics Teacher* **33**, 502–506.

Henderson C.R. (2002) Common concerns about the Force Concept Inventory. *Physics Teacher* **40**, 542–547.

Hestenes D., Wells M. & Swackhamer G. (1992) Force Concept Inventory. *Physics Teacher* **30**, 141–158.

Hewitt P.G. (1997) *Conceptual Physics*, 8th edn. Addison-Wesley, Reading, MA.

van Joolingen W.R., de Jong T. & Dimitrakopoulou A. (2007) Issues in computer supported inquiry learning in science. *Journal of Computer Assisted Learning* **23**, 111–119.

Kalyuga S., Chandler P. & Sweller J. (1998) Levels of expertise and instructional design. *Human Factors* **40**, 1–17.

Kalyuga S., Ayres P., Chandler P. & Sweller J. (2003) The expertise reversal effect. *Educational Psychologist* **38**, 23–31.

Lee J., Dineen F., McKendree J. & Mayes T. (1999) Vicarious learning: cognitive and linguistic effects of observing peer discussion. Paper presented at the American Educational Research Association, Montréal, Québec, Canada.

Limon M. (2001) On the cognitive conflict as an instructional strategy for conceptual change: a critical appraisal. *Learning and Instruction* **11**, 357–380.

Lowe R. (2004) Interrogation of a dynamic visualization during learning. *Learning and Instruction* **14**, 257–274.

McClosky M. (1983) Intuitive physics. *Scientific American* **248**, 122–130.

McDermott L.C. (1991) What we teach and what is learned – closing the gap. *American Journal of Physics* **59**, 301–315.

McDermott L.C. & Shaffer P.S. (2001) *Tutorials in Introductory Physics*. Prentice Hall, Upper Saddle River, NJ.

MacIsaac D., Cole R.P., Cole D.M., McCullough L. & Maxka J. (2002) Standardized testing in physics via the World Wide Web. *Electronic Journal of Science Education* **6**. Available at: http://ejse.southwestern.edu/original%20site/manuscripts/v6n3/articles/art02_macisaac/macisaac.pdf (last accessed 12 June 2007).

McKendree J., Stenning K., Mayes T., Lee J. & Cox R. (1998) Why observing a dialogue may benefit learning. *Journal of Computer Assisted Learning* **14**, 110–119.

Mayer R.E. (2001) *Multimedia Learning*. Cambridge University Press, Cambridge.

Mayer R.E. (2003) The promise of multimedia learning: using the same instructional design methods across different media. *Learning and Instruction* **13**, 125–139.

Mayer R.E. (2004) Teaching of subject matter. *Annual Review of Psychology* **55**, 715–744.

Mayer R.E. (Ed.) (2005) *The Cambridge Handbook of Multimedia Learning*. Cambridge University Press, Cambridge.

Mayer R.E. & Jackson J. (2005) The case for coherence in scientific explanations: quantitative details can hurt qualitative understanding. *Journal of Experimental Psychology Applied* **11**, 13–18.

Mayer R.E., Bove W., Bryman A., Mars R. & Tapangco L. (1996) When less is more: meaningful learning from visual and verbal summaries of science textbook lessons. *Journal of Educational Psychology* **88**, 64–73.

Mazur E. (1997) *Peer Instruction: A User's Manual*. Prentice Hall, Upper Saddle River, NJ.

Muller D.A. (2005) Inside the quantum mechanics lecture: changing practices. Paper presented at the Higher Education Research and Development Society of Australasia, Sydney, Australia. Available. at: http://conference.herdsa.org.au/2005/pdf/refereed/paper_260.pdf (last accessed 12 June 2007).

Paas F., Tuovinen J.E., Tabbers H. & Van Gerven P.W.M. (2003) Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist* **38**, 63–71.

Posner G.J., Strike K.A., Hewson P.W. & Gertzog W.A. (1982) Accommodation of a scientific concept: toward a theory of conceptual change. *Science Education* **66**, 211–227.

Ramlo S. (2002) The force and motion conceptual evaluation. Paper presented at the Annual Meeting of the Mid-Western Educational. Research Association, Columbus, OH.

Redish E.F. & Steinberg R.N. (1999) Teaching physics: figuring out what works. *Physics Today* **52**, 24–30.

Ronen M. & Eliahu M. (2000) Simulation – a bridge between theory and reality: the case of electric circuits. *Journal of Computer Assisted Learning* **16**, 14–26.

diSessa A.A. (1996) What do 'just plain folk' know about physics? In *Handbook of Education and Human Development: New Models of Learning, Teaching and Schooling* (ed. D.R. Olson), pp. 705–730. Blackwell Publishers, Cambridge, MA.

diSessa A.A. (2006) A history of conceptual change research: threads and fault lines. In *Cambridge Handbook of the Learning Sciences* (ed. K. Sawyer), pp. 265–282. Cambridge University Press, Cambridge.

Sharma M.D., Mendez A. & O'Byrne J.W. (2005) The relationship between attendance in student-centred physics tutorials and performance in University examinations. *International Journal of Science Education* **27**, 1375–1389.

Sweller J. (1994) Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction* **4**, 295–312.

Sweller J., van Merriënboer J.J.G. & Paas F.G.W.C. (1998) Cognitive architecture and instructional design. *Educational Psychology Review* **10**, 251–296.

Tabbers H.K., Martens R.L. & van Merrienboer J.J.G. (2004) Multimedia instruction and cognitive load theory: effects of modality and cueing. *British Journal of Educational Psychology* **74**, 71–81.

Thornton R.K. & Sokoloff D.R. (1998) Assessing student learning of Newton's laws: the force and motion conceptual evaluation of active learning laboratory and lecture curricula. *American Journal of Physics* **66**, 338–352.

Trowbridge D.E. & McDermott L.C. (1980) Investigation of student understanding of the concept of velocity in one dimension. *American Journal of Physics* **48**, 1020–1028.

Trowbridge D.E. & McDermott L.C. (1981) Investigation of student understanding of the concept of acceleration in one dimension. *American Journal of Physics* **49**, 242–253.

Vosniadou S. (1994) Capturing and modeling the process of conceptual change. *Learning and Instruction* **4**, 45–69.

Vosniadou S. & Verschaffel L. (2004) Extending the conceptual change approach to mathematics learning and teaching. *Learning and Instruction: The Conceptual Change Approach to Mathematics Learning and Teaching* **14**, 445–451.

Vosniadou S., Ioannides C., Dimitrakopoulou A. & Papademetriou E. (2001) Designing learning environments to promote conceptual change in science. *Learning and Instruction* **11**, 381–419.

Weaver G.C. (1998) Strategies in K-12 science instruction to promote conceptual change. *Science Education* **82**, 455–472.

Yeo S., Loss R., Zadnik M., Harrison A. & Treagust D.F. (2004) What do students really learn from interactive multimedia? A physics case study. *American Journal of Physics* **72**, 1351–1358.

Young H.D. & Freedman R.A. (2000) *University Physics with Modern Physics*, 10th edn. Benjamin-Cummings, San Francisco, CA.

Zacharia Z.C. (2007) Comparing and combining real and virtual experimentation: an effort to enhance students' conceptual understanding of electric circuits. *Journal of Computer Assisted Learning* **23**, 120–132.