

Increasing student engagement in physiology – the use of simple spinal reflex animations

Richard Guy

School of Medical Sciences, RMIT University, PO Box 71, Bundoora VIC 3083, Australia

Summary

1. Simple spinal reflex animations were developed to help overcome a common student misconception that the brain is part of spinal reflex pathways. A low cognitive load approach and best practice principles were used to generate stretch reflex, Golgi tendon reflex and withdrawal reflex animations. Resting membrane potential, graded responses and action potentials were represented by a simple colour code rather than by complex voltage-time graphs.

2. Pre-test post-test evaluation indicated a significant improvement in student understanding of spinal reflexes. Although this improvement cannot be entirely attributed to the animations they were successful in engaging the students with 92% of students surveyed (n=85) agreeing that the animations were a useful aid to their learning.

3. The benefits of the low cognitive approach and advantages and disadvantages of using physiology analogies (including animations) as a student-learning tool are discussed.

Introduction

Physiology is an important (core) component of many health sciences programs and it is critical that students understand the basic concepts. However student engagement with physiology has emerged as a significant problem in recent years. Lack of engagement in turn leads to poor learning outcomes.¹ This study is based on the idea that reducing the cognitive load of instructional material will lead to increased student engagement.²

The ineffectiveness of traditional forms of teaching (*e.g.* lectures, summary diagrams and electrophysiological recordings) can be seen when some students continue to believe that the brain is an essential component of a spinal reflex pathway. Continuing anecdotal indicators from student verbal feedback and examination answers suggest that misconceptions may be deep seated.³ One method that has been suggested as a way of improving student engagement and understanding is the use of physiology analogies. Analogies have been used as a means of reducing cognitive load by providing students with a simpler, more tangible, representation than that offered by “target” concepts. Analogies range from students acting out a concept,⁴ to those that attempt to closely model the actual physical processes involved.⁵ Effective analogies may lead to improved engagement and learning,⁶ and for this reason a set of animations was developed to promote student engagement in and understanding of spinal reflexes.

The widespread use of e-learning has promoted the

use of animations and multimedia instruction and there is a common view that animations provide an effective means of learning. However improper use of e-learning tools may lead to less than ideal environments.⁷ A survey of computer animations in medical education found that some animations increased extraneous cognitive load and reduced germane cognitive load.⁸ To avoid some of these issues the spinal reflex animations were developed using a low cognitive load approach. This was based on a best practice e-learning strategy that incorporated load reduction,⁹ simplification of navigation, a primarily visual format, interactivity (active learning) and feedback.¹⁰ Student evaluation of the animations was used to assess the level of engagement.

Methods

The student sample

The animations were developed and used by students taking a second year undergraduate physiology course. The neurophysiology component was taught over a three-week period and provided a comprehensive coverage of nervous system function including one lecture on spinal reflexes. These students had received introductory lectures on the nervous system during their first year.

Development of the e-learning module

A trial version of *EnactEd* (*‘Enact Education’*) was used to develop the e-learning module. *EnactEd* was developed at RMIT University to allow academics to create online learning activities. The animations were developed in association with the RMIT Educational Development Unit and were based on Adobe Flash software.

Multiple-choice questions

Each animation was associated with a multiple-choice question related to a particular reflex (the same questions used in the pre and post-tests). The distractors were developed using student feedback and common student misconceptions in written exam answers. For each question the distractors included one that specifically indicated that the brain was a critical component of a spinal reflex pathway *e.g.* (following stretch of a skeletal muscle) “sensory receptors in the muscle send signals to the brain and the brain sends signals back to the muscle to cause it to contract”.

Stretch reflex

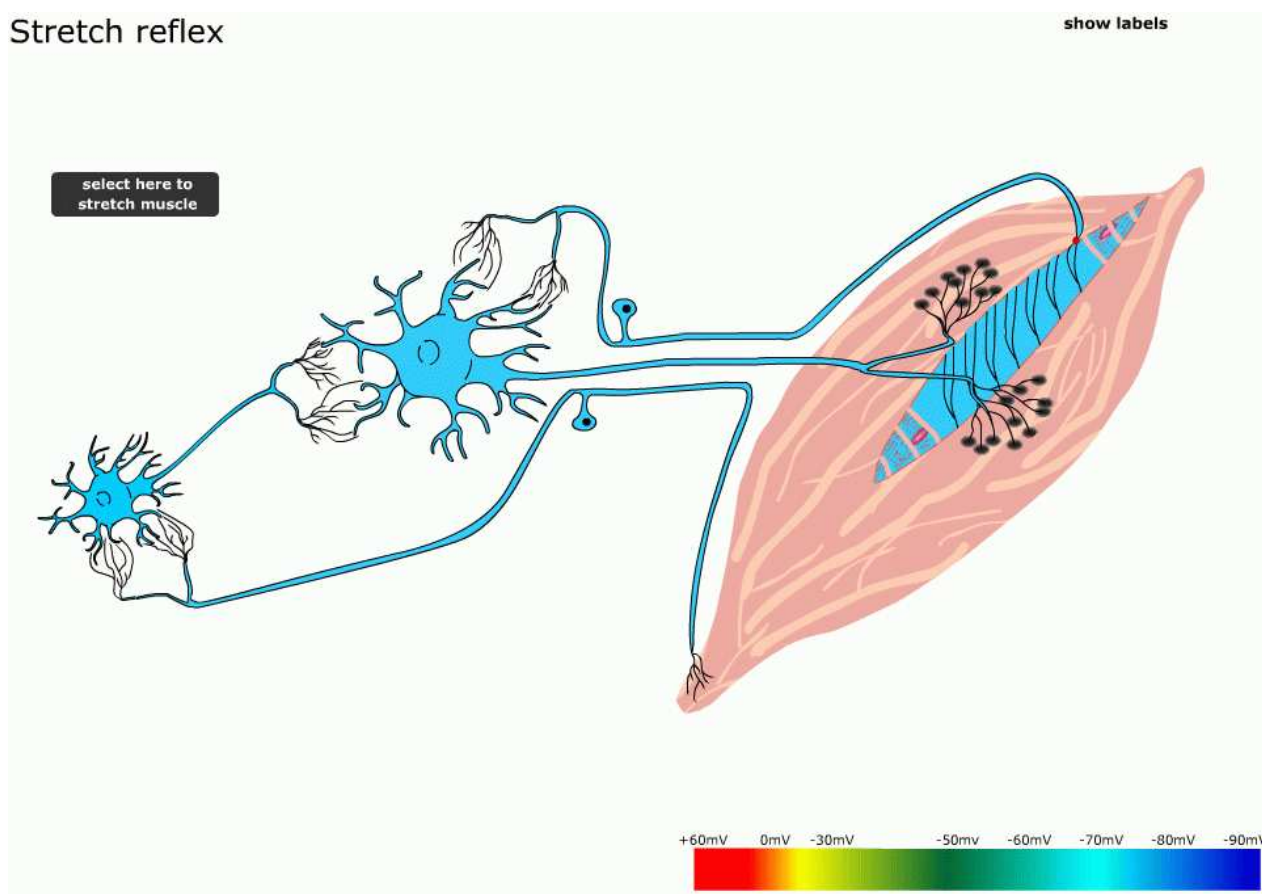


Figure 1. Template for stretch and Golgi tendon reflexes. The stretch reflex animation was based on the muscle spindle sensory neuron, the motoneuron and the muscle. The Golgi tendon reflex animation also included the Golgi tendon sensory neuron and the interneuron. Each of the two reflex animations was initiated by clicking on a “stretch muscle” icon. Synaptic potentials were represented by graded colour changes and action potentials were represented as red dots (maximum positive potential) passing along the axons. All potential changes were referenced against a colour-voltage scale bar. Labels could be shown or switched off.

Neurophysiology animations

Validation

Three animations were developed to support understanding of the stretch reflex, the Golgi tendon reflex and the withdrawal reflex. The main purpose of the animations was to demonstrate that spinal reflexes are based on simple neuronal arrangements *i.e.* that the brain is not part of the reflex loop. To reduce cognitive load a simple arrangement of neurons and muscle cells was used with the first two reflexes sharing the same template. Reduced load was also achieved by limiting movement to voltage changes and muscle contraction. Membrane potential changes were shown as simple graded colour changes rather than as complex voltage-time displays. A colour bar was provided that matched the colour against the potential (Figure 1). Resting membrane potential was coded by a single uniform colour. Synaptic potentials were represented by graded changes in colour. Action potentials were represented by a colour equivalent to the peak potential. The animations ran

at slow speed to allow time for the students to observe the potential changes and sequence of events. Labels were provided to assist understanding of the reflex components but in line with the low cognitive approach they could be switched off to reduce potential distraction. Academic peer-review was used to ensure that the animations were suitable for their intended purpose.

Stretch Reflex

The stretch reflex animation template is shown in Figure 1. The reflex pathway consists of a single muscle spindle sensor in the muscle which projects to a single motoneuron. The motoneuron in turn projects back to the body of the muscle. The background blue colour of the neurons indicates resting membrane potential. Activation of the reflex (by clicking on a “stretch muscle icon”) caused muscle stretching and stimulation of the muscle spindle sensor. Action potentials were shown as red dots (maximum positive potential) passing along the sensory axon to the axon terminals. The motoneuron dendrites and cell body

Withdrawal reflex

show labels

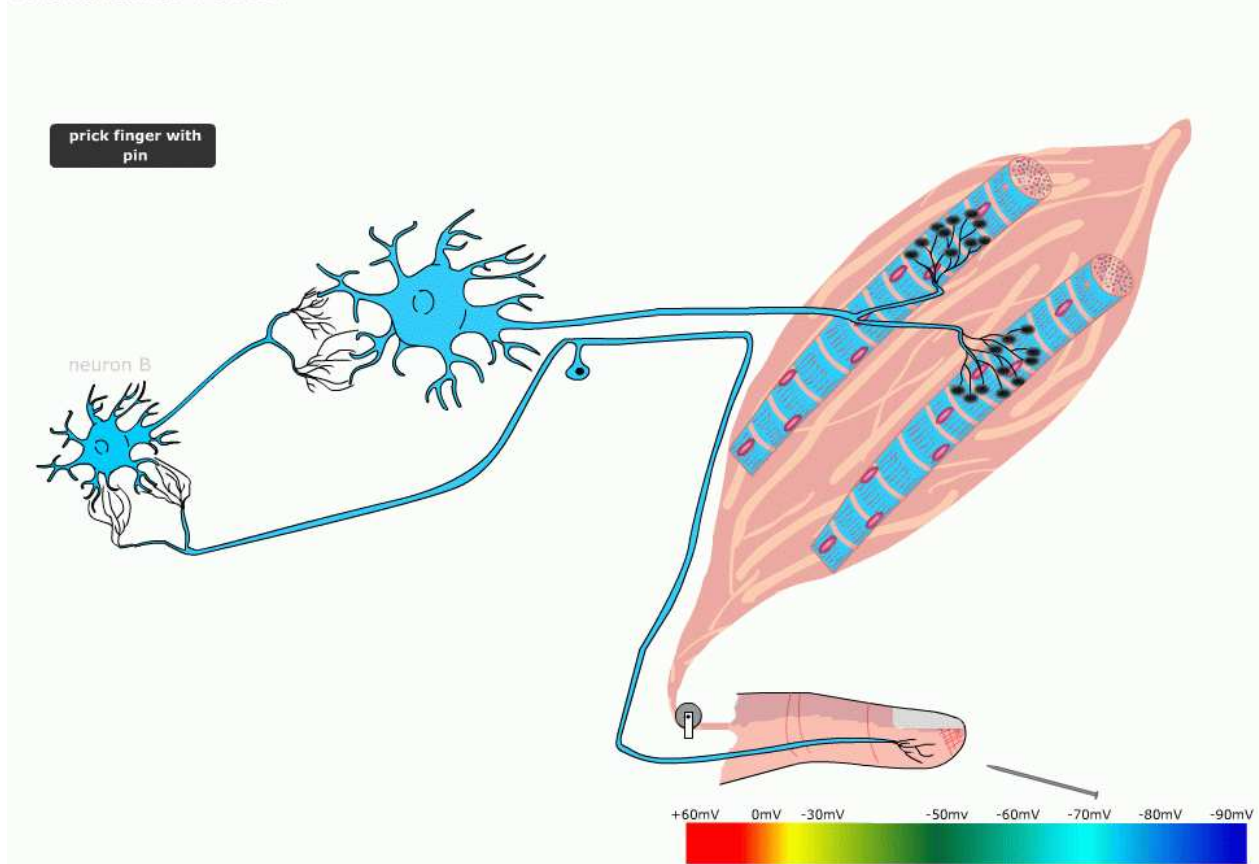


Figure 2. Template for withdrawal reflex. The withdrawal reflex animation was based on the skin sensory (pain) neuron, the interneuron, the motorneuron and the muscle. The reflex animation was initiated by clicking on a “prick finger” icon that triggered the movement of the pin into the finger. Reflex output was indicated by muscle contraction and withdrawal of the finger. Synaptic potentials were represented by graded colour changes and action potentials were represented as red dots (maximum positive potential) passing along the axons. All potential changes were referenced against a colour-voltage scale bar. Labels could be shown or switched off.

showed an excitatory post-synaptic potential (EPSP - graded green colours) that generated action potentials. These potentials passed to the muscle and produced an EPSP (graded green colours) and generation of action potentials (maximum positive potential - red lines) and muscle contraction.

Golgi tendon reflex

The Golgi tendon reflex is a separate animation using the template shown in Figure 1. The reflex pathway consists of a single Golgi tendon organ which projects to a single interneuron. The reflex was initiated in a similar fashion to the stretch reflex but with a larger stretch. In addition to the stretch reflex activation described above the Golgi tendon organ receptor was also activated and action potentials passed to the axon terminals. The interneuron was activated and showed a (colour-coded) postsynaptic potential and action potentials. The interneuron in turn produced an inhibitory postsynaptic potential (IPSP) in the motorneuron (graded dark blue colours). The IPSP and muscle spindle

initiated EPSP cancelled each other and no output was produced by the motorneuron (no muscle contraction).

Withdrawal reflex

A pin entering the finger initiated reflex activation (Figure 2). Stimulation of a single pain sensor caused action potentials to pass to the sensory axon terminals. These initiated an EPSP (graded green colours) and action potentials in an interneuron. The interneuron in turn activated the motorneuron by generating an EPSP. The EPSP generated action potentials that passed to the muscle and caused muscle contraction and finger withdrawal.

Delivery and testing protocol

The students were given access to the animations during the neurophysiology component. Before the module started the students completed three multiple-choice questions (as part of a larger test) related to the animations to gauge the degree of “prior knowledge”. The same three

questions were also completed six weeks later after the end of the neurophysiology component. The same questions were also linked to the online animations. A non-parametric Friedman test was used to establish significant differences between the pre and post-test data. At the end of the semester students were surveyed with respect to their opinion of the animations.

Results

Pre-test

Each of three multiple-choice questions was answered correctly by approximately 50% of the students (stretch reflex – 50%; Golgi tendon reflex – 53%; withdrawal reflex – 50%). The correct answers indicated that sensory signals were sent to and integrated within the spinal cord before the production of a motor output (or blocking of the motor output in the case of the Golgi tendon reflex). For the stretch reflex and the Golgi tendon reflex approximately 20% of the students indicated that the spinal reflex pathway involved the brain, and in the case of the withdrawal reflex 40% of the students considered the brain was part of the reflex pathway.

Amongst the cohort of students 22% answered all questions correctly, 27% answered 2/3 questions correctly, 27% answered 1/3 correctly and 24% failed to answer any questions correctly.

Post-test

The post-test results indicated a significant increase in the percentage of correct answers for all three spinal reflex questions (stretch reflex – 82%; Golgi tendon reflex – 79%; withdrawal reflex – 89%). The post-test results were significantly different from the pre-test results in each case (Non-parametric Friedman test $P < 0.001$, pre-test $n = 74$; post-test $n = 28$). Amongst the post-test cohort of students 61% answered all questions correctly, 28% answered 2/3 correctly and 11% answered 1/3 correctly or failed to get any correct.

Final Survey

A final survey found that 92% of the students agreed that the animations were effective in explaining neurophysiological concepts ($n = 85$). No students were found who disagreed with this statement.

Discussion

The idea of starting with fundamentals and building up to more complex concepts in physiology would be regarded by most as a reasonable strategy.¹¹ However finding a way to present fundamental concepts in a way that will engage the students is not straightforward. The use of a low cognitive load approach appears to provide a useful starting point. Although the cognitive load of the spinal reflex animations was not measured a best practice approach to reducing load was used where colour changes replaced voltage-time plots and where unnecessary

information was removed. In addition some degree of active learning was provided where students were able to select and activate the animation of choice and receive feedback via coupled multiple-choice questions. The results of this study are encouraging with respect to student engagement.

Pre-intervention assessment indicated (in line with anecdotal evidence) that a significant proportion of students considered the brain to mediate spinal reflexes (for all three reflexes). Post-intervention assessment indicated a significant increase of correct answers in these areas from a pre-test average value of about 50% to a post-test average of between 79% and 89%. The fact that the post-test value was not higher might be related to the difficulty in overcoming misconceptions once they have become established.³ It is possible that these misconceptions result from first year classes where the importance of the brain in sensory processing and motor control is stressed. The improvement appears to be representative of the cohort (rather than being restricted to a particular subgroup) as the number of students answering all three questions correctly rose from a pre-test value of 22% to a post-test value of 61%. As the students also had access to other learning resources between the pre and post-test it is not possible to attribute the improvement in learning to the animations alone. However the animations were certainly effective in engaging the students as 92% of those surveyed agreed that the animations were an effective learning aid.

Very few studies have tested the effectiveness of physiology analogies. For example Breckler and Yu,¹² used a pre-test post-test method to show improved student learning following the use of a blood oxygen carrying analogy. Only two studies have used a control group to ascertain the learning effect of an analogy. In one case the analogy was shown to be effective,¹³ and in the other it achieved a similar effect to comparative text-based materials.¹⁴ Although it is important to assess the effectiveness of physiology analogies it is also important to understand that they are likely to be most effective when used in conjunction with other learning resources.¹⁴

The success of the spinal reflex animations may, in part, be attributed to the combination of active learning with a visual and movement approach. These strategies are a common feature of physiology analogies *e.g.* the online animated model of glomerular filtration rate.¹⁴ Interactivity is a key component of any online system,¹⁰ and it provides a basis for active learning as it increases learner interest, cognitive processing and curriculum integration. Active learning can be achieved in other analogies, outside of the online environment, by physical manipulation of objects *e.g.* manipulating springs to illustrate physiology principles,¹⁵ or by acting out physiology concepts.⁴ A key component of the spinal reflex animations is the use of a visual approach and our own work and that of many others has indicated that many students have a visual preference for the intake of information.⁹ The neurons in the animation are clearly represented and labels can be “switched off” to reduce cognitive load. Colour is another important aspect of the spinal reflex animations and our replacement of voltage-time plots with a colour code serves two important

functions. Firstly it provides a more visual representation of voltage changes and secondly colour itself can provide an important element in student engagement and interest. Colour has been used successfully to separate individual anatomical structures and to avoid confusion in the interpretation of complex anatomical images.¹⁶ In some instances colour codes have been found to improve achievement in complex self-paced visual tasks.¹⁷ Colour has also been used to facilitate neuroscience learning. Milanick,¹⁸ used a colour analogy to represent membrane potential with the relative role of the Na⁺ and K⁺ gradients represented by red or blue liquid. It is interesting that, in line with the present study, the use of more complex analogies was avoided. It was felt that the use of colour would avoid the use of physical and mathematical terms (as seen in the membrane potential spring analogy¹⁵).

The need for more assessment of analogy learning outcomes stems from criticism that animations may unnecessarily reduce relevant cognitive load associated with deeper meaningful cognitive processes.² Students may accept a “naïve” (*i.e.* highly simplified) version of a threshold concept,¹⁹ without following any further avenues of investigation. For this reason it is important to establish the links between analogy and target concept to make sure that the analogy itself does not become the essence of student understanding. Some might regard the degree of simplification and abstraction present in the animations as too distant (semantically speaking) from the target to be useful. For example the withdrawal reflex pathway used in the current study is a simplification of a “real” withdrawal reflex where multiple muscles are used. In line with this the water-tower analogy of the cardiovascular system,⁵ has been criticised on the basis that it differs in fundamental respects to the system it is trying to represent.²⁰ Most analogies (including animations) probably include significant differences to the target concept. However we would argue that once the basic concepts are established the animations can still be useful by getting the students to make a comparison between the animation and the target. In other words they can critique the animations by making a comparison with the target. This analogical reasoning is a useful learning strategy.²¹

This study has shown that it is possible to use a low cognitive load best practice approach to generate engaging physiology animations in an online learning environment.²² However one cannot assume that physiology analogies will always improve student learning and rigorous testing should be implemented to ensure useful outcomes.

Acknowledgements

I would like to thank the following RMIT staff for their help with this project: Kylie Williams – Multimedia Producer and Flash Animator; Amanda Burgess – Flash Animator; Angela Nicolettou – Educational Design; John Milton – Curriculum Innovation and Development; Jary Nemo – Project Manager EnactEd; April Weiss – Distributed Learning Systems. I would also like to thank the reviewers, Professor Phil Poronnik, Professor Trevor

Anderson and Dr Bruce Byrne for helpful comments.

References

1. McWilliam E, Poronnik P, Taylor P.G. Re-designing science pedagogy: Reversing the flight from science. *J. Sci. Educ. Technol.* 2008; **17**: 226-235.
2. Sweller J, van Merriënboer JGG, Paas F. Cognitive architecture and instructional design. *Educ. Psychol. Rev.* 1998; **10**: 251-296.
3. Michael J. Misconceptions – what students think they know. *Adv. Physiol. Educ.* 2002; **26**: 5-6.
4. Yucha CB. Understanding physiology by acting out concepts. *Adv. Physiol. Educ.* 1995; **14**: S50-S54.
5. Swain DP. The water-tower analogy of the cardiovascular system. *Adv. Physiol. Educ.* 2000; **24**: 43-50.
6. Schonborn KJ, Anderson TR. Bridging the educational research-teaching practice gap: Conceptual understanding, part 2: Assessing and developing student knowledge. *Biochem. Molec. Biol. Educ.* 2008; **36**: 372-9.
7. Kirschner PA, Ayres P, Chandler P. Contemporary cognitive load theory research: The good, the bad and the ugly. *Computers Hum. Behav.* 2011; **27**: 99-105.
8. Ruiz JG, Cook DA, Levinson AJ. Computer animations in medical education: a critical literature review. *Med. Educ.* 2009; **43**: 838-46.
9. van Merriënboer JJ, Sweller J. Cognitive load theory in health professional education: design principles and strategies. *Med. Educ.* 2010; **44**: 85-93.
10. Deubel P. An investigation of behaviourist and cognitive approaches to instructional multimedia design. *J. Educ. Multimedia Hypermedia* 2003; **12**: 63-90.
11. Anderson TR, Schonborn KJ. Bridging the educational research-teaching practice gap: Conceptual understanding, part 1: The multifaceted nature of expert knowledge. *Biochem. Molec. Biol. Educ.* 2008; **36**: 309-15.
12. Breckler J, Yu JR. Student responses to a hands-on kinesthetic lecture activity for learning about the oxygen carrying capacity of blood. *Adv. Physiol. Educ.* 2011; **35**: 39-47.
13. Cosgrove JF, Fordy K, Hunter I, Nesbitt ID. Thomas the Tank Engine and Friends improve the understanding of oxygen delivery and the pathophysiology of hypoxaemia. *Anaesthesia* 2006; **61**: 1069-74.
14. Gookin JL, McWhorter D, Vaden S, Posner L. Outcome assessment of a computer-animated model for learning about the regulation of glomerular filtration rate. *Adv. Physiol. Educ.* 2010; **34**: 97-105.
15. Cardozo DL. A model for understanding membrane potential using springs. *Adv. Physiol. Educ.* 2005; **29**: 204-7.
16. Khalil MK, Paas F, Johnson TE, Payer AF. Interactive

- and dynamic visualizations in teaching and learning of anatomy: a cognitive load perspective. *Anat. Rec. B New Anat.* 2005; **286**: 8-14.
17. Lamberski RJ, Dwyer FM. The instructional effect of coding (color and black and white) on information acquisition and retrieval. *Educ. Commun. Technol.* 1983; **31**: 9-21.
 18. Milanick M. Changes of membrane potential demonstrated by changes in solution color. *Adv. Physiol. Educ.* 2009; **33**: 230.
 19. Meyer JHF, Land R. Threshold concepts and troublesome knowledge (2): Epistemological considerations and a conceptual framework for teaching and learning. *Higher Educ.* 2005; **49**: 373-388.
 20. Badeer HS. Is the water-tower analogy justified? *Adv. Physiol. Educ.* 2001; **25**: 187-188.
 21. Agis-Torres A, Lopez-Oliva E. Criticizing models as a strategy to help students understand hemodynamics and develop their critical abilities. *Adv. Physiol. Educ.* 2007; **31**: 119-20.
 22. Ayres P, Paas F. Making instructional animations more effective: a cognitive load approach. *Appl. Cogn. Psychol.* 2007; **21**: 695-700.

Received 13 May 2011, in revised form 21 September 2011. Accepted 20 January 2012.

© R. Guy 2011.

Author for correspondence:

Dr Richard Guy
School of Medical Sciences,
RMIT University, PO Box 71,
Bundoora VIC 3083, Australia

Tel: +61 3 9925 7595

Fax: +61 3 9925 7075

E-mail: richard.guy@rmit.edu.au