EXAMPLECASTS: THE UNREASONABLE EFFECTIVENESS OF WEBCAST WORKED EXAMPLES IN INTRODUCTORY UNIVERSITY PHYSICS

Paul Francis[a,b]

Presenting Author: Paul Francis (paul.francis@anu.edu.au)
[a]Physics Education Centre, Research School of Physics and Engineering, The Australian National University, Canberra 0200, Australia
[b]Research School of Astronomy and Astrophysics, The Australian National University, Canberra 0200, Australia

KEYWORDS: online learning, worked examples, problem solving strategies, first year transition

ABSTRACT
This paper described the use of examplecasts. I record a video of myself solving a complex physics problem. I solve it 'cold' - unprepared, and hence make mistakes and recover from them. The videos record me writing on an iPad or tablet, and my vocal description of what I am doing. Students watch the videos, then answer quick online multiple-choice questions which are worth token marks.

The examplecasts are very popular, and led to large increases in the fraction of students using good problem-solving strategies in the final exam. Such strategies include describing in words (not just equations) what physical principles they are using, and checking their answers. The webcast worked examples seem to ease the transition of students from high-school physics to the more challenging problems of university physics.

Proceedings of the Australian Conference on Science and Mathematics Education, Australian National University, Sept 19th to Sept 21st, 2013, pages 136-141, ISBN Number 978-0-9871834-2-2.

INTRODUCTION
The motivation for the examplecasts described in this paper came from some frustrated students. I teach a physics course which is the first course students do when they come to university. The prospect of doing physics at university is a scary one for many students, and so I tried to make the first homework assignment reassuringly easy. Every year, however, a considerable fraction of the students find it impossibly hard. Each year I make it easier, but still many students find it impossible.

One possibility is that there is something uniquely hard about physics problems. Why might physics be particularly difficult? Cognitive load theory suggests one possible answer. This theory posits that for many classes of task, students are limited primarily by the small working memory capacity of the human brain (e.g. Miller, 1956; Sweller 1994; Paas, Renkl, & Sweller, 2003; Paas & van Gog, 2006). Physics and maths problems pose particularly high demands on working memory (e.g Sweller, 1988), due to strong inter-connectedness of the different elements of a given problem: students have to simultaneously keep in mind the starting state, the desired outcome, the physical principles required, with all their limitations, and the details of the various algebraic tricks. One proposed solution is to teach problem solving not by doing problems, but by studying worked examples, which has been shown in multiple studies to improve learning (e.g. Sweller, van Merrienboer, & Paas, 1998; Paas &van Gog, 2006), at least for novice students (Kalyuga, Ayres, Chandler, & Sweller, 2003). By working through a worked example, the students could focus on and understand one step at a time. Unfortunately, anecdotal evidence suggested that most students in my class did not work through the many provided worked examples step by step. Instead, they tended to skim through them looking for a key equation.

The second possible reason why students found even the easiest problems impossible was that there might be some concept or skill which was so obvious to me that I wasn't explaining it to the students. It is a well-known educational problem that experts can jump to conclusions without conscious awareness of what they are doing (e.g. Larkin, McDermott, Simon, & Simon, 1980). My own experience as a novice learner in another domain (building a garden deck) suggested that this could indeed be a problem (most books used terminology I did not understand or assumed familiarity with techniques which I did not possess). But this experience also suggested a possible solution: when I was baffled by some instruction, I would search out a video on Youtube, where I could actually see precisely what was meant.

The idea I came up with was to record a video of me solving a physics problem. In these “examplecast” videos I would solve the problem “cold” - i.e. with no preparation. This means I would make mistakes, go down wrong tracks and then hopefully recover. I would record absolutely everything I did, so that hopefully whatever it was that I was not explaining would be made clear to the students. I would talk while I was writing, explaining what I was doing and why. The video format makes it much harder for students to skip quickly through looking for key equations, but still allows them to focus on one step at a time, to re-watch key bits and pause to think, thus meeting the requirements of cognitive load theory. Note that this is rather different from standard lecture recordings (a technique which has been much discussed - e.g. Yunus, Kasa, Asmuni, Samah, Napis, Yusoff, Khanafie, & Wahab, 2006).

I would encourage the students to watch these videos by asking them to answer a few simple on-line questions based on the video, and worth some token marks. The videos would be short (5-10 minutes) so I wouldn’t have to accept student complaints about how long it took to do the homework. After watching the webcasts, the students would then solve similar problems with step-by-step online guidance, and would finally solve them unguided.

In this paper, I will start off with some background information on the course in which these examplecasts were used. I will describe how we evaluated the effectiveness of these videos, outline the technologies used to produce them, and then draw conclusions.

BACKGROUND

The examplecasts were used in the core calculus-based first year physics class at the Australian National University, taken by 250-300 students with a strong high-school maths and physics background. 40% of the students plan on majoring in science, while the remaining 60% are engineering students taking it as a service course. The webcasts were used in the first half of the course, covering mechanics.

The course uses peer instruction in lectures (Crouch & Mazur 2001), together with collaborative problem-solving tutorials (loosely based on the SCALE-UP model, Gaffney, Richards, Kustusch, Ding, & Beichner, 2008). The conceptual learning of the students was assessed using the force concept inventory (Hestenes, Wells, & Swackhamer ,1992), and for several years the normalised gains achieved have been over 60%.

Despite all this, student performance in the final exams remained deeply disappointing. We used ‘context rich’ problems, based on those produced by the University of Minnesota (Heller & Hollabaugh, 1992). Typical student responses had no diagram, random equations appearing from nowhere, and absolutely no comments on even the most ridiculous answers.

Our first attempt to improve student problem-solving performance in this course involved mastery learning and was documented by Francis, Figl, and Savage (2009). As described in that paper, it was not a success: we realized that unless we focussed on teaching students a sensible problem-solving strategy, more time-on-task would be pointless.

Our second attempt (in 2010) involved teaching an explicit problem-solving strategy in lectures, mentoring tutors to push the use of this strategy, and explicitly building assessment of use of this strategy into all homework and exam questions. As will be described below, this had some success. Our third attempt (in 2011) is the subject of this paper.

EVALUATION TECHNIQUES AND RESULTS

First, an apology. I had no idea that the webcasts would be as effective as they turned out to be, and so at the time had no intention to publish an evaluation of their effectiveness. The evaluation techniques described here are thus just those we routinely use for quality control.

Examplecasts were first deployed in the very first week of the first semester of first year. Anecdotal evidence of their power appeared shortly afterwards, in the weekly meetings the lecturers hold with tutors. Several tutors were reporting that students were spontaneously adopting a much better problem-solving strategy than they had ever seen before. There were reports of students checking their answers for plausibility *without being asked*! This had never been seen before by even the most experienced tutors. Furthermore, we no longer seemed to have a sub-set of students finding the first homework impossibly hard.

Four weeks later, I inserted a survey into the weekly on-line homework, asking students how useful they found various aspects of the course. The results (Figure 1) showed that the students rated the examplecasts very highly - indeed comparable to traditional (online) homework, and ahead of the problem-solving tutorials.

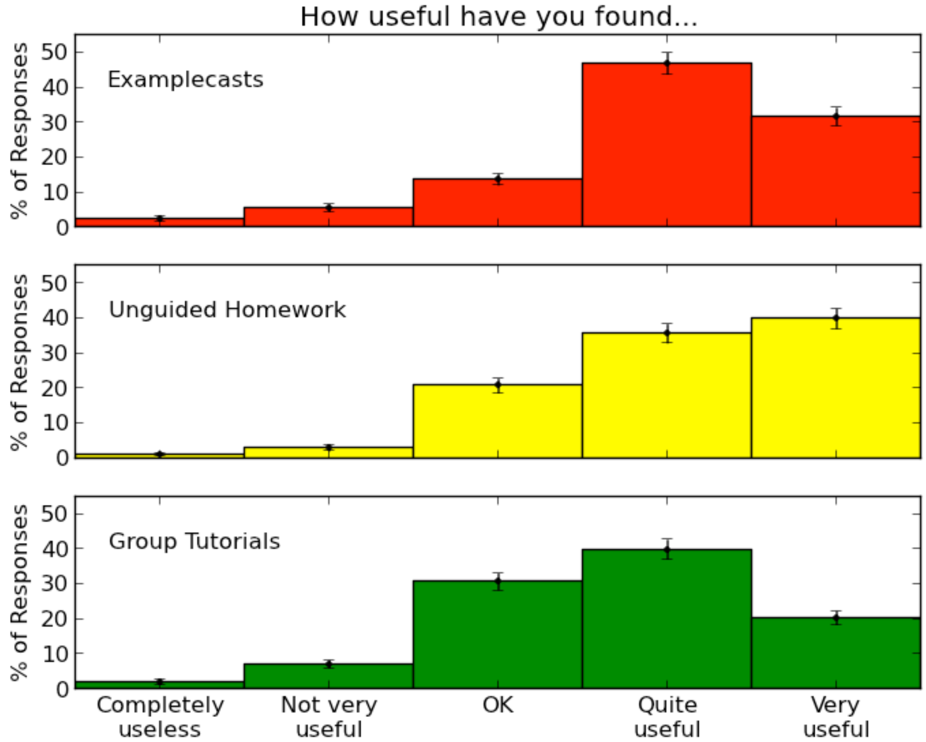

Figure 1. Distribution of student responses to the question "How useful have you found…" for the three labeled aspects of the course. Data shown is the sum of responses in 2012 and 2013. Survey was completed by 474 students, which is 84% of enrolled students.

Students were also asked two open ended questions about what they liked most and any suggestions for improvement. A large fraction of students commented on the examplecasts, and their comments give some flavor of why they liked them. Here is a sample of representative comments (complete with original spelling…):

> *I really enjoyed the webcast and Paul's homework questions, because the webcast involved Paul talking through a problem, which is a technique I tried after I heard him do it and it really helps me solve complex mechanics problems!! The problem solving strategy was also very helpful.*

> *The webcasts were really good for revision/help for other questions but I didn't really learn all too much from them other than how to approach problems. But since that is what they are probaly for that is good,*

> *The webcasts were most valuabe by a long shot for me. Watching someone else do a problem and explaining the steps of thinking was very helpful.*

> *The webcasts were definitely fantastic.*

The webcasts were perhaps the most useful way to learn I have ever come across. Very informative and helpful, as well as accessable.

I think that the web casts were probably the best part about this course, since I could watch how to solve these problems in my own time, at my own pace, and i could rewind, and watch some of the stuff that I missed, or pause it if I didn't understand it. This was really helpful.

The final and most important evaluation came from the final exam. Each year I pull out 100 exam papers and classify them by the problem-solving strategies used. Each solution is classified on whether an appropriate diagram was drawn, whether the student explained in words what physical principles they were using, rather than just writing down random equations, and on whether there was any evidence that their answers and working had been checked. The results for 2009, 2010 and 2011 are shown in Figure 2.

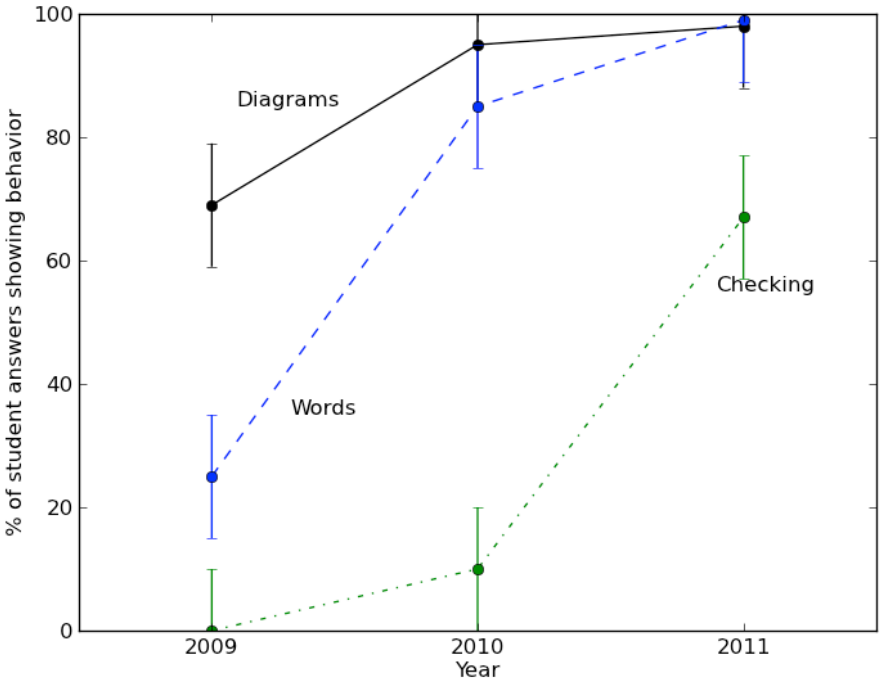

Figure 2: Percentage of student exam responses showing appropriate diagrams, words to explain the physical principles used, and evidence of explicit checking. Based on a sample of 100 exam questions in each of the three years surveyed. No special instruction in the problem-solving strategy was used in 2009. In 2010 it was taught explicitly and built into the marking schemes. In 2011 this continued, and in addition the examplecasts were used.

The dramatic improvement in the fraction of students showing a sensible problem-solving strategy in the exam can be clearly seen. Some of the improvement came in 2010, presumably due to explicitly teaching a problem-solving strategy and building it into the marking criteria. And there was a further big jump in 2011, which we tentatively ascribe to the examplecasts.

A caveat - while formally very statistically significant (if only Poisson sampling uncertainties are considered), any year-by-year comparison like this must be treated with some suspicion, as it is impossible to rule-out many other possible sources of year-on-year variability.

PEDAGOGY AND TECHNOLOGY

Over the three years I've been producing examplecasts, both the technology used and the detailed pedagogy have evolved considerably as I've learned from my mistakes and from student feedback. Early webcasts can be seen at Francis (2011), while later ones can be seen at Francis (2012) and Francis (2013).

PEDAGOGY
The first videos were around 15 minutes long, and were totally unscripted - I really did solve the problems unprepared, and make numerous mistakes. I included absolutely everything in my recordings - all the algebra steps and all the calculator steps.

Student feedback rapidly made it clear that I didn't need to include the calculator steps, but that the algebra steps were crucial. Cutting calculator steps out dropped the length of the typical webcast to 5-10 minutes, which seems to work well.

I have experimented with different levels of scripting. If I solve the problem ahead-of-time and then repeat it on-screen, I get a much slicker and shorter video. But I am not showing how to recover from mistakes, and tend to gloss over details that are obvious to me. Even when solving problems unprepared, I find that I have to concentrate hard on explaining all the steps as I make them - this does not come naturally.

Recording, editing and uploading a ten minute clip would typically take an hour.

RECORDING TECHNOLOGY
The first examplecasts were produced using an iPad and stylus. It is not possible to write very small on an iPad, which can be a problem if long equations or many lines of working are involved. In these cases I pause the recording and start a new page. On the other hand, the large writing means that the videos can be compressed down to very small sizes while still being perfectly clear. This means they work well for students with low bandwidth internet or viewing them on smaller mobile devices.

The videos are recorded using the 'Explain Everything' app, which also records what I am saying while doing the problem using the iPad microphone. The sound quality is surprisingly good, but sometimes too quiet, so I typically split the audio off from the video using Quicktime, and then compress the sound (i.e. reduce the dynamic range) using the program Audacity.

More recently, I have been using a Wacom Cintiq tablet, which allows me to write smaller and more precisely over a larger area. I write using the Sketchbook Pro program, and capture the sound using a slightly more expensive (~ $50) headphone mounted microphone. A head-mounted microphone has two advantages - it stays a constant distance from your mouth as you move your head, which gives a more uniform volume, and because it is closer to your mouth it is better at rejecting background noise. Camtasia is used to record and edit the video and sound. Its editing system is very good and allows you to cut out gaps, zoom in on key areas and remove 'ums' and 'ahs' in post-production. This combination of a tablet with Camtasia produces somewhat better videos at a considerably greater price.

The finished videos look much like those on the Khan academy (http://www.khanacademy.org), in that they are hand-written with a voice-over. The difference is that the Khan academy videos are explaining concepts, while my examplecasts are worked examples.

PUTTING THE WEBCASTS ON THE WEB
At first, I used Quicktime to convert the videos into a web-streaming format and then uploaded them to a local server. The main issue with this was that a small fraction of students using older Windows computers had trouble viewing the videos, so I had to post them in several different formats.

More recently, I just upload the videos to Youtube. This means that no students have any trouble viewing the videos, and also provides a useful place for students to comment on them. I upload them in high definition and Youtube automatically provides the option of viewing them in lower resolution.

ALTERNATIVES
Perfectly acceptable examplecasts could be produced in many other ways. Writing on paper in a document camera can work well, as can putting a video camera on a tripod pointed at a black- or white-board. There are also cheaper tablet options which can work well.

CONCLUSIONS
Why are the examplecasts so effective? Partially it is probably the reasons we introduced them initially: they expose every step of problem solving, including ones we are temped to gloss over in

lectures, and they force students to pay attention to each step in the problem while minimising cognitive load. Students say that they like the ability to replay tricky bits repeatedly, and they very much value watching me go through all the algebraic steps. Indeed it may well be that a big reason why students were originally finding my homework hard was their poor algebra skills. Many students also mention the intimacy of the format (something usually missing in a large class), commenting that watching the videos is like having me sit down beside them to explain a problem. They also comment that the voice-overs are helpful by exposing the thought processes behind the equations - an aid to meta-cognition. All these factors probably contribute at some level.

My students now have a good conceptual understanding of physics, as measured by the force concept inventory (normalised gains still over 60%), and a good problem-solving strategy, as measured by their exam answers. Does this mean that the students can now solve complex context-rich problems? They do show good conceptual knowledge and good problem-solving strategies, but this does not seem to be enough.

The remaining problem seems to be the well-known issue of educational transfer. Students can do problems that have surface features very similar to the examples they have done before, but have enormous difficulty applying this knowledge to structurally similar problems with different surface features (e.g. Barnett & Ceci, 2002; Willingham, 2007). Unfortunately, introductory physics has so many applications in such a range of diverse areas that it is impossible to expose students to even a tiny fraction of the possible scenarios in which they may be called upon to use their knowledge. Thus transfer is really important, and improving it is our next challenge (e.g. Hesketh, 2003).

ACKNOWLEDGEMENTS

I would like to thank many members of the Physics Education Centre, past and present, for innumerable useful discussions. Particular thanks go to Craig Savage, Anna Wilson, Joseph Hope, Kate Wilson, Ruth Mills, Kim Heenan, Mika Kohonen, John Close, Cristina Figl, and to all the tutors who helped with the course.

REFERENCES

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

Barnett, S. M. & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer, *Psychological Bulletin, 128*, 612-637.

Francis, P. J. (2011). *PHYS1101 2011 webcasts*. Retrieved June 12, 2013, from http://www.mso.anu.edu.au/~pfrancis/phys1101/questions/index.html.

Francis, P. J. (2012). *PHYS1101 2012 webcasts*. Retrieved June 12, 2013, from http://www.mso.anu.edu.au/~pfrancis/phys1101/webcasts/.

Francis, P. J. (2013). *ANU FIrst Year Physics Youtube Channel*. Retrieved June 12, 2013, from http://www.youtube.com/channel/UC5m-vgnrYeIpJAJFBvLaqNQ.

Francis, P. J., Figl, C., & Savage, (2009). Mastery learning in a large first-year physics class. In A. Hugman (Ed.), *Proceedings of the Motivating Science Undergraduates: Ideas and Intervention,* (p152). Sydney, NSW: UniServe Science.

Gaffney, J. D. H., Richards, E., Kustusch, M. B., Ding, L., & Beichner, R., (2008), Scaling up educational reform, J*ournal of College Science Teaching, 37*, 48.

Heller, P. & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups, *American Journal of Physics, 60*, 637.

Hesketh, B. (2003). The Science of Teaching and Learning. In A. Fernandez (Ed.), *Proceedings of the Scholarly Inquiry in Flexible Science Teaching and Learning* Sydney, (pp. 3-6). Sydney, NSW: UniServe Science.

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

Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The Expertise Reversal Effect, *Educational Psychologist, 38*, 23-31.

Larkin, J., McDermott, J., Simon, D. P., & Simon, H. A. (1980). Expert and Novice Performance in Solving Physics Problems, *Science, 208*, 1335.

Miller, G. A., (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information, *Psychological Review,* 63, 81-97.

Paas, F. & van Gog, T. (2006). Optimising Worked Example Instruction: Different Ways to Increase Germane Cognitive Load. *Learning and Instruction* 16, 87–91.

Paas, F, Renkl, A., & Sweller, J. (2003). Cognitive Load Theory and Instructional Design: Recent Developments. *Educational Psychologist* , *38*, 1–4.

Sweller, J. (1988). Cognitive Load During Problem Solving: Effects on Learning. *Cognitive Science, 12*, 257-285

Sweller, J. (1994). Cognitive Load Theory, Learning Difficulty, and Instructional Design. *Learning and Instruction, 4*, 295–312.

Sweller, J. Van Merrienboer, J. J. G. & Paas, F. G. W. C. (1998). Cognitive Architecture and Instructional Design, *Educational Psychology Review,* 10, 251-296.

University of Minnesota, *context rich problems.* Retrieved June 12, 2013, from http://groups.physics.umn.edu/physed/Research/CRP/crintro.html.

Willingham, D.T. (2007). Critical Thinking: Why is it so hard to teach? *American Educator, Summer 2007, 8,* 8-19.

Yunus, A., Kasa, Z., Asmuni, A., Samah, B., Napis, S., Yusoff, M., Khanafie, M., & Wahab, H. (2006). Use of webcasting technology in teaching higher education, *International Education Journal, 7*, 916.