Australian Government

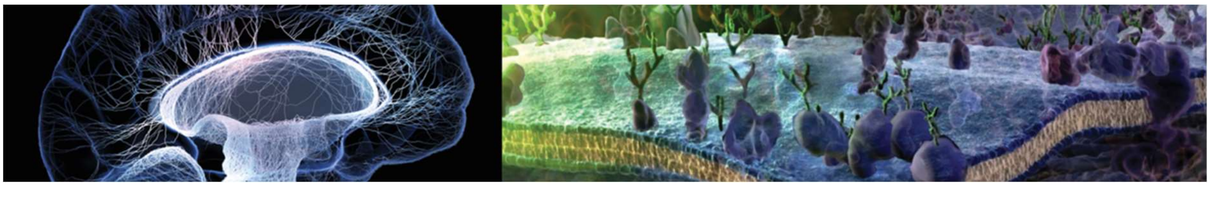
Department of Education and Training

Research into practice:
evidence-informed, best-practice visualisation for a deeper understanding of science

Final report 2019

Lead institution: Western Sydney University

Project leader: Professor Roy Tasker



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List of acronyms used

ACDS	Australian Council of Deans of Science
ACSME	Australian Conference on Science and Mathematics Education
ANU	The Australian National University
CLT	Cognitive Load Theory
CSU	Charles Sturt University
CUBEnet	Collaborative Universities Biomedical Education Network
NSTF	National Senior Teaching Fellowship
OLT	Office for Learning and Teaching
RACI	Royal Australian Chemical Institute
SFS	Student feedback surveys
UQ	The University of Queensland
UTS	University of Technology Sydney
UWS	University of Western Sydney
VisChem	The VisChem Project – Visualizing Chemistry

Executive summary

Project context

For most people, learning science involves imagining *invisible* phenomena—such as molecular-level structures and processes, force fields and energy changes—to explain *observable* experiences—like stickiness, magnetic repulsion and hot objects—in order to create new insights. Mental modelling of these imperceptible phenomena through visualisation is the key to making meaning from the symbolism and mathematics in science that too often alienate novice students. Only when you have useful visual mental models of these invisible phenomena can you see the power of mathematics to generalise from the specific, and meaningfully communicate about these phenomena using scientific shorthand (symbols, formulas, equations), terminology, and language.

Visualisation in science is usually complex and dynamic, so it is cognitively demanding. Consequently, best-practice use of visualisation in science teaching should be informed by the latest cognitive science research on factors determining how the brain perceives, processes, stores and retrieves audiovisual information, and ways to ameliorate this load. We also need to encourage learners to communicate their visual models orally, in writing, and through storyboards (labelled drawings), to probe for misconceptions.

The unique aspect of this fellowship was to stimulate strategic and embedded use of visualisation in science teaching by applying findings in learning research in three distinct disciplines—science education, multimedia education and cognitive science—whose practitioners rarely read one another's published research or attend one another's conferences.

The idea for the fellowship was prompted by the success of the biennial *Gordon Research Conference on Visualisation in Science and Education* involving these three communities, and the creative and intellectual outcomes that have resulted in its 16-year history.

Aims of the project

This Senior Fellowship is leading a national conversation on *what*, *why* and *how* to visualise concepts for learning science. In each of eight national workshops in Australia and New Zealand, participants experienced and applied best-practice design principles for presenting static and dynamic visualisations. They were exposed to a learning design for how to use them in their teaching, based on a cognitive learning model that has broad acceptance in the science education community. As a summative workshop outcome, they applied what they learned by embedding their own visualisation of a challenging threshold concept in a learning design.

The first stage of the fellowship involved a study tour to visit key centres of excellence in the production of visualisations in a range of science disciplines, and research groups developing the latest pedagogy for using them most effectively in teaching. The best examples were presented to inspire workshop participants and show what is possible for developing student understanding through imagination and visualising dynamic data.

Project outputs and deliverables

The fellowship concluded with a national forum at which a selection of participants showcased their work. The project web site (*sciencevis.com.au*) continues to provide a gallery of exemplary visualisations collected during the study tour and available on the internet, in addition to a list of key references to the literature on topics covered in the fellowship. A video of a presentation of the cognitive learning model and its implications for devising a learning design is available on the home page, with copies of all the presentation slides on the workshops page.

Key findings

An independent, comprehensive evaluation study was conducted to measure the outcomes of the fellowship and their impact on the workshop participants and the broader tertiary science education community through their discipline networks.

The findings listed below are useful and instructive for other educators planning to conduct a fellowship involving professional development with a teaching innovation.

The following points are extracted from the summary statements written by the authors of the evaluation.

- Of the major goals set out in Prof Roy Tasker's NSTF Fellowship application for which there is sufficient data to evaluate, 10 out of 11 were achieved or exceeded their stated outcomes, which is representative of the overall success of the fellowship.
- The main focus of the fellowship program was the workshop series. The number of planned workshops was exceeded by 25% and the workshops were well received by attendees. Retention of workshop ideas was high, while implementation of ideas was, in some cases, not higher than in the wider educational community.
- The main suggestion from the evaluators for future fellowship programs was to boost the uptake of workshop ideas into educators' personal teaching strategies. This could have been achieved by the implementation of the stated goal of wider community engagement online through social media and an active blog. This was the only goal of the fellowship that was not successfully implemented. However, in the evaluators' opinion, this would not be significant to the outcome as blogs are generally most effective at raising awareness and informing, which was already achieved by other aspects of the fellowship program.
- Significantly impacting educators' teaching strategies is highly aspirational and difficult to achieve. In this case, there were limitations in the structure of the fellowship, being workshop-based to a wide audience of voluntary participants. In order to achieve greater impact in changing the personal teaching habits of educators, the evaluators suggest future fellowship programs more deeply engage entire faculty-wide groups. This is a promising strategy, given the success of this fellowship in instilling the importance of these teaching practices in the individual faculty members who participated.

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Chapter 1: Project background, context and aims

Overview

This chapter describes the vital role that visualisation plays in learning science. For most people, the invisible causal phenomena used to explain events in the observable world need to be visualised to be understood. This visualisation is a bridge to interpret the abstract symbolism and mathematics used to describe these causal phenomena. Visualisation is usually complex and dynamic, so it is cognitively demanding. Consequently, best-practice use of visualisation in science teaching should be informed by the latest research on the factors contributing to this cognitive load, and ways to ameliorate this load. The chapter concludes with the aims and deliverable outcomes of this fellowship to disseminate best-practice visualisation in tertiary science education.

The importance of visualisation in understanding science

Learning science involves explaining observable phenomena—such as magnetism, stickiness and warmth—using models of their invisible causes (for these examples, force fields, molecular-level interactions and energy changes). Mental modelling of these causal phenomena requires visualisation. Only when learners have useful visual mental models of these invisible causes can they make meaning from the scientific shorthand (symbols, formulas, equations) and terminology used to represent them. This is necessary to appreciate the power of mathematics to generalise these models to generate new insights.

These ideas are illustrated in Figure 1 using an example from the *VisChem* project in chemistry (Tasker & Dalton, 2006). Here, the observable phenomenon is the formation of silver crystals on a metallic copper surface in a chemical reaction. In the chemist's mind's eye, the processes involved in the formation of silver atoms on the surface of copper atoms are imagined at the invisible molecular level. These processes are then communicated using conventional symbolism – formulas and equations. The abstraction of the symbolic level, with its lack of obvious meaning, is a major cause of confusion and alienation for novices and leads to many curious and imaginative minds rejecting chemistry as an intellectual pursuit.

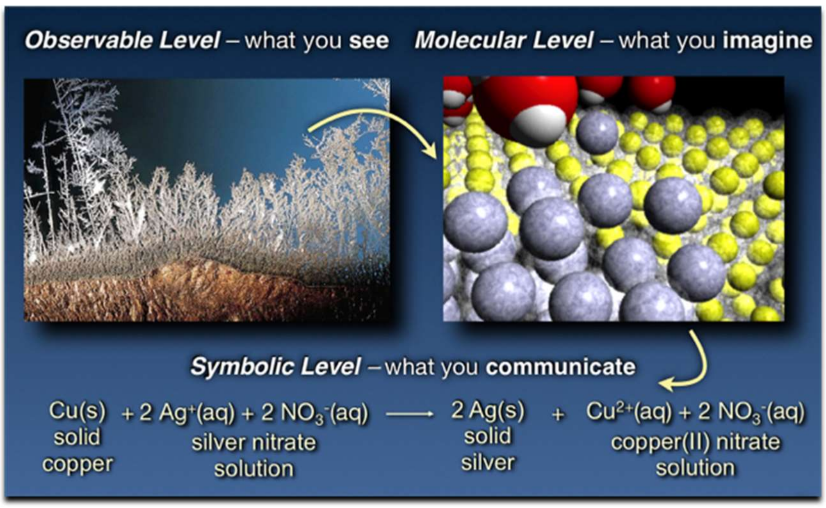

Figure 1. An example of the three thinking levels in chemistry. The visible formation of the dendritic silver crystals is explained by the invisible transfer of electron cloud from the copper atoms (yellow) to the silver ions (grey), and the whole reaction is summarised in an abstract chemical equation.

Best-practice visualisation informed by a cognitive learning model

This Senior Fellowship led a national conversation on *what*, *why* and *how* to visualise the invisible explanatory models in science. These models are cognitively challenging, so their best-practice visualisation should be informed by the latest cognitive science research on the factors determining how the brain perceives, processes, stores and retrieves audiovisual information. Figure 2 illustrates the cognitive learning model (Johnstone, 2006; Mayer & Moreno, 2003) presented in the fellowship workshops. This model describes how audiovisual information is first perceived and filtered by the brain, then processed in the working memory to generate new ideas, and the new ideas integrated with prior learning in the long-term memory. Knowing the factors affecting each stage of the process, a sequence of learning activities (a learning design) can be devised to address each stage—priming the perception filter, reducing cognitive load and facilitating elaborate idea linking.

The first challenge is to prepare the mind for new information; this requires understanding the affordances and constraints imposed by the perception filter. This knowledge is essential for generating motivation for the learner to engage in the topic, and recognising the need to prime this filter for pre-conceptions (and possibly misconceptions). The initial activities in the learning design should, therefore, motivate the learner and elicit pre-conceptions.

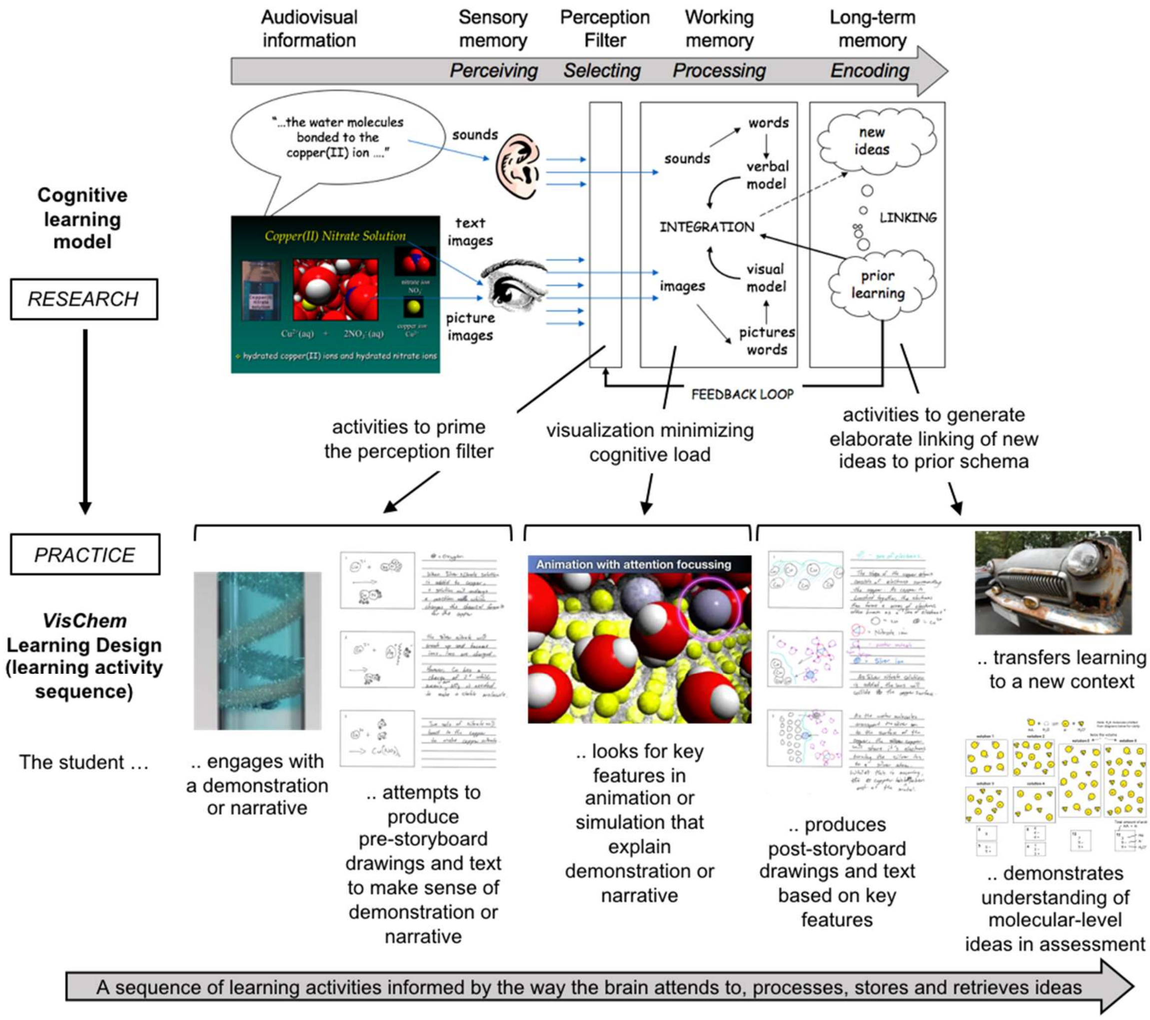

Figure 2. A sequence of learning activities devised for the stages in the cognitive learning model.

The second challenge is to present the audiovisual information in such a way as to minimise the cognitive load imposed on the limited-capacity working memory. Strategies include segmenting the visualisation, simplifying where possible and appropriate and focusing attention on key features. The third challenge is to provide learning activities that enable elaborate linking of the new ideas generated to existing schema in the long-term memory.

Fellowship aims, objectives and deliverables

The major aims of this Fellowship were to

- both *inform* and *embed* the above evidence-based visualisation pedagogy with tertiary science educators, providing opportunities for them to apply the pedagogy to one or more learning topics in their own teaching and science discipline context, and
- collect and disseminate examples of innovative visualisations from centres of excellence in scientific visualisation to inspire science educators.

To achieve these aims, the objectives and deliverables of the fellowship were to:

- undertake a study tour in the United States to visit centres of excellence in the production of visualisations and their use in tertiary science education, in a range of sciences;
- conduct workshops for tertiary science educators in Australia and New Zealand to:
    - show why visualisation of causal phenomena is so important for understanding science at a deep level,
    - demonstrate how the cognitive learning model informs best practice in presenting *external*[1] representations of models through visualisations,
    - explore strategies for communicating *internal*[1] representations by constructing visualisations using labelled drawings (storyboards) and simulation software, and
    - support participants to develop and share a learning design with their own visualisation of a threshold concept they find challenging to teach.
- produce a dedicated web site for the fellowship with a gallery of visualisation exemplars available on the internet and from the study tour; a database of formative and summative assessment activities to elicit internal visualisations (e.g., drawing storyboards) to reveal student mental models; and an updateable list of key references to the research literature on topics covered in the fellowship;
- host a national forum to promote an evidence-based approach to using visualisation in science teaching;
- establish an active *community of visualisation practice*, sustained by the science education discipline networks (*ChemNet*, *SaMnet*, the *CUBE* and *VIBE* networks) and the Australian Council of the Deans of Science; and
- disseminate the outcomes and deliverables of the fellowship on the website, through presentations at national and international science education conferences, and by using the tertiary science education discipline networks and the Australian Council of the Deans of Science.

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[1] *External* representations are available to others; *internal* representations are only available to an individual. The making of meaning for any representation is *visualisation*.

Chapter 2: Approach and methodology

Overview

This chapter summarises the approach and methodology used to achieve the objectives of the fellowship in sufficient detail to be useful for others interested in promoting a new teaching approach to the tertiary science education community.

Study tour

A study tour of centres of excellence in scientific visualisation in the USA was conducted to collect examples of visualisations in a broad range of science disciplines. The choices of places to visit were provided by colleagues in the community of practice sustained by the biennial *Gordon Research Conference on Visualisation in Science and Education*. These visits took place between 6 October and 13 November 2014 to establish a network of experts to share with the Australian community of visualisation practice on the Fellowship website and included:

- Purdue University—meeting with Trevor Anderson and colleagues to learn more about his *Visualisation in Biochemistry Education (VIBE)* project.
- The *National Centre for Supercomputing Applications* at the University of Illinois, Urbana Champaign—meeting with Donna Cox and her colleagues, who produce impressive visualisations of meteorological and astronomical phenomena based on massive data sets (Advanced Visualisation Lab).
- Columbia University Teachers College—meeting with Barbara Tversky and her students, who investigate the cognitive demands of visualisation in all its forms.
- Harvard University—meetings with:
    - George Whitesides and his group with an international reputation for innovation, creativity and expertise in visualisation of complex phenomena.
    - Gael McGill and his production team (Digizyme), which specialises in the production of 3D animations of biochemical phenomena.
    - Eric Mazur and his teaching team with an international reputation in research-informed teaching using peer learning and other strategies to engage students.
- MIT—meetings with:
    - Felice Frankel, a scientific artist who works with George Whitesides (see above) and specialises in making visualisation in science more efficient and effective through communication of internal visualisations using student drawings (Picturing to Learn).
    - Lourdes Aleman, a molecular biologist who has developed multimedia resources in biochemistry for teaching.
- Scripps Research Institute—meeting with Art Olsen, David Goodsell and their research team in the Olsen Laboratory, developing novel visualisation techniques for the computation, analysis and modelling of the interaction of protein–ligand, protein–protein and other biomolecular systems

- University of Santa Barbara—meeting with two cognitive scientists with expertise in learning from audiovisual multimedia:
    - Mary Hegarty, who studies mechanical reasoning and interpretation of graphics, using eye-fixation data to trace the processes involved in understanding visual-spatial displays (diagrams, graphs and maps) and making inferences from these displays.
    - Richard Mayer, who studies multimedia learning, such as determining how people learn scientific explanations from computer-based animation, video and narration, and how people learn to solve problems from interactive simulations.
- University of San Francisco—meeting with Graham Johnson (Mesoscope Project), who is leading a project to generate, simulate and visualise molecular models of cells.
- University of California, Berkeley—meeting with Marcia Linn (TELS Project), who has developed evidence-based pedagogies for learning science through visualisation.
- University of Illinois, Chicago—meeting with Mike Stieff, who conducts research on spatial thinking and diagrammatic reasoning in scientific problem solving, the interaction between visuospatial ability and scientific expertise, and model-based reasoning in science.

Workshops—methodology

The fellowship program aimed to both *inform* and *embed* evidence-based visualisation pedagogy in tertiary science education teaching. To achieve this, a series of one-day workshops was conducted in 2015 at central city locations around Australia, one location in Wellington, New Zealand, and one location at the University of Utah, USA.

These workshops were designed to be informative, interactive and participatory, modelling best-practice teaching strategies (e.g., using audience response technology) and guided by the implications of the cognitive learning model that was the focus of the content.

Enlisting participants

The first step was to contact 'critical friends of the fellowship', with one chosen to host the workshop at each central location in the capital cities of Queensland, the Australian Capital Territory, New South Wales, Victoria, South Australia and Western Australia. The workshops were held at:

- the **University of Technology, Sydney** (hosted by Shirley Alexander), with support from Manjula Sharma and Siegbert Schmidt at The University of Sydney, Ian Jamie at Macquarie University and Glennys O'Brien at Wollongong University
- the **Monash Conference Centre** (hosted by Tina Overton), with support from Liz Johnstone, then at La Trobe University
- the **University of Queensland** (hosted by Gwen Lawrie), with support from Madeleine Schulz at the Queensland University of Technology

- **Curtin University** (hosted by David Treagust), with support from Bob Bucat at The University of Western Australia and Magda Wajrak and Ron Oliver at Edith Cowan University
- **Flinders University** (hosted by Karen Burke da Silva), and
- the **Australian National University** (hosted by Stephen Jones and Craig Savage), with enthusiastic support from Janelle Wheat at Charles Sturt University.

In addition to the promotional efforts of the critical friends above, for each venue email invitations (see Appendix B) were sent to the Deputy Vice-Chancellors (Teaching and Learning) or equivalents in all the surrounding universities, requesting their support and cooperation in forwarding the invitation to the appropriate executive academics who could promote the workshop within their departments. The invitation was particularly targeted at attracting enthusiastic early-career lecturers and part-time sessional staff (tutors, lab supervisors and demonstrators), as they were most likely to be open to new ideas in teaching, were the future of science education, and were directly involved at the teaching coalface.

The invitation indicated when and where the workshop was held, with the pre-workshop requests for attendees to:

- bring a laptop computer to access websites and for embedding a visualisation activity into a learning design
- install a free 60-day licensed copy of *Odyssey* simulation software (sponsored by *Wavefunction Inc.)* for use in the late afternoon workshop activity. The installation instructions and an access code were provided when the participant registered
- bring a complex visualisation resource of some kind—anything from a complex static diagram, photograph, or graphic to a dynamic simulation, animation or movie
- have thought of a difficult science concept that could be visualised as a mental model during the workshop using their complex visualisation resource.

Workshop program

The workshop program (see Appendix C for complete handout) is described in Table 1 on the next page. The morning session was divided into two parts. The first part involved an interactive presentation of the cognitive learning model (see Figure 2) and its implications for using visualisations in a sequence of learning activities (a *learning design*). The learning design for this presentation was itself informed by the cognitive learning model to demonstrate the approach, and audience response technology was used to facilitate peer discussion. The second part of the workshop was a group activity to embed each participant's visualisation in a learning activity within a learning design based on the cognitive learning model.

The afternoon session also had two parts. The first part continued the group development activity started before lunch, to get to the point where the activity could be completed after the workshop if necessary. The second part involved demonstrations of compelling visualisations collected during the study tour, with a whole-group discussion of how they might be best presented using the cognitive learning model. The final activity was to demonstrate the effectiveness of using storyboards to elicit students' prior internal visualisations. Participants were asked to complete an online evaluation survey before leaving the workshop, if possible. The evaluation data for each workshop were used to modify and improve the following workshop.

As an incentive to complete their learning design an enduring copy of the *Odyssey College Instructor Edition* software, valued at USD600, was awarded for the best learning design incorporating an activity using this simulation software.

Fellowship website

The dedicated website (*ScienceVis.com.au*) provides a gallery of exemplary external visualisations collected during the study tour and available on the internet, in addition to an updateable list of key references to the literature on topics covered in the fellowship. A video of the presentation of the cognitive learning model and its implications for devising a learning design is available on the home page, with copies of all the presentation slides on the workshops page.

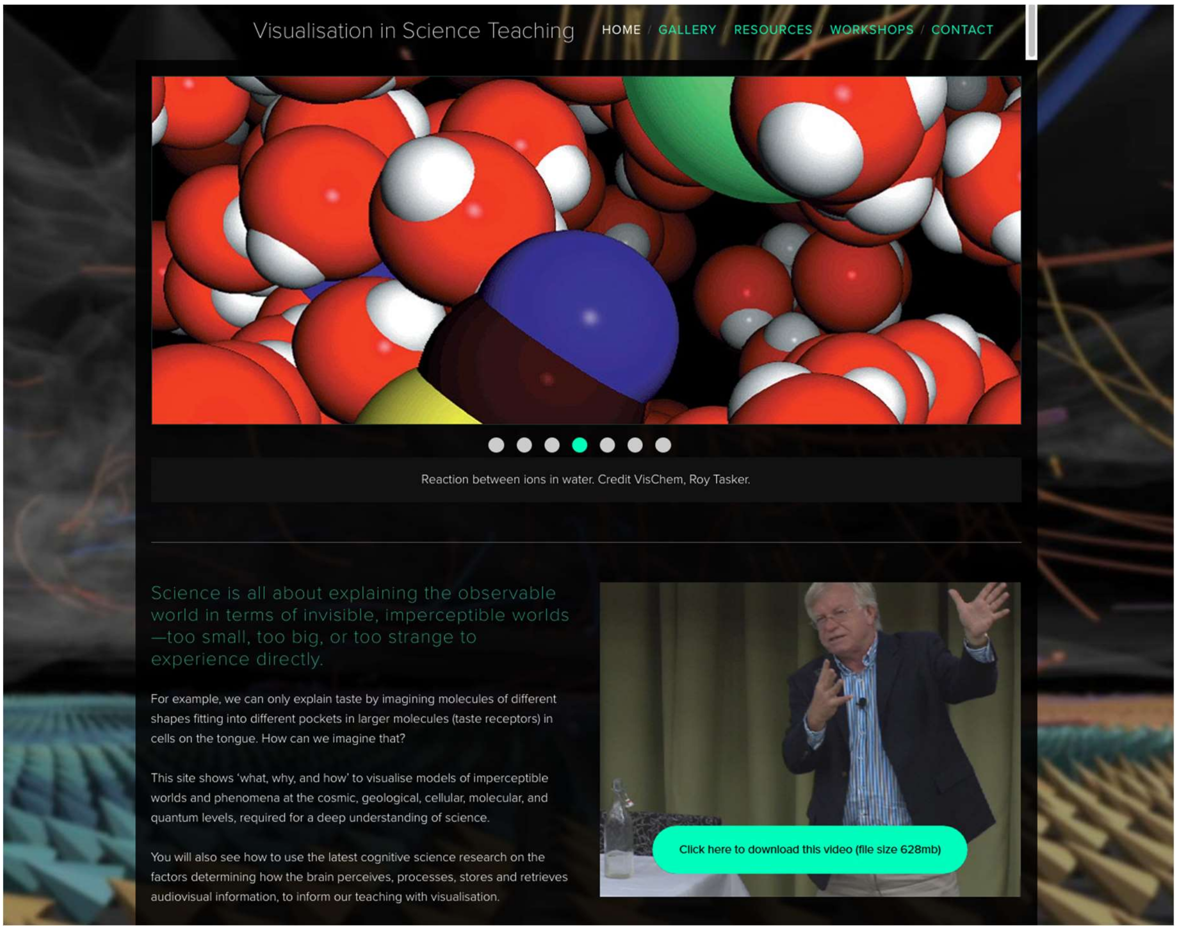


Figure 3. Video on the home page on the fellowship website demonstrating the cognitive learning model and its implications for presenting visualisations. Other pages include a gallery of exemplary visualisations from various science disciplines and a preliminary list of publications in the literature grouped by science discipline.

A dedicated *Facebook* site was established to foster ongoing communication between participants and as a vehicle to broaden interest in the topic.

National Forum on Visualisation in Science Teaching

The one-day conference held on 14 July 2015 at the University of Technology, Sydney was designed to promote a national conversation on the importance of evidence-based visualisation in science education, and present some outcomes from the fellowship workshops. The program is shown in Table 1 below:

Table 1. The program for the national forum with the topics and questions addressed.

Time	Activity	Topic and Questions Addressed
10:00 – 11:00	Opening Keynote: **Richard Lowe** Professor of Learning Technologies Curtin University	Dynamic visualisations: Can they revolutionize science education? • *What are the benefits of dynamic visualisations for teaching science?* • *Who should influence the design of these dynamic visualisations and why?*
11:00 – 11:30	Interactive Presentation 1: **Gwen Lawrie**	Work, heat and internal energy: a visualisation to make abstract concepts more concrete
11:45 – 12:15	Interactive Presentation 2: **Margaret Wegener**	Electricity in animals: Concepts of electric charge, field and potential, related to muscle activity
12:15 – 12:45	Interactive Presentation 3: **Faye Paioff**	Role play to understand methods of heat transfer in lower school science
12:45 – 1:15	**LUNCH**	
1:15 – 1:45	Interactive Presentation 4: **Garry Hoban**	Student-generated blended media to explain and communicate science
1:45 – 2:15	Interactive Presentation 5: **Paul Abbott**	Visualisation and computation of aspects of electromagnetism
2:30 – 3:00	Interactive Presentation 6: **Stewart Walker**	Visualizing the un-demonstrate-able
3:00 – 3:50	Closing Keynote: **Roy Tasker** Professor of Chemistry Education University of Western Sydney	Research into Practice: Evidence-informed, best-practice visualisation for a deeper understanding of science • *why is a visual mental model often necessary before a mathematical model?* • *how can we assess deep understanding through visualisation?*
3:50 – 4:00	Future Prospects + fanciful promises to continue the conversation	Continuing the conversation and disseminating good ideas through the ***sciencevis.com.au*** website and ***Visualisation in Science Teaching*** Community Facebook site • *how can we generalise good practice using visualisations across multiple disciplines?* • *how can we keep up with developments in science visualisation and new insights from cognitive science?*

Chapter 3: Impact and findings

Overview

This chapter describes the impact of the fellowship and draws on key findings in the comprehensive evaluation conducted independently by **Professor Manjula Sharma** and **Dr Scott Cornish** at The University of Sydney. The overall aim was to learn what worked and what didn't, as a useful guide for future professional development programs of this kind. **This chapter is in their words.**

Objectives of evaluation

The objectives of the evaluation were to determine:

- whether the **outcomes** of the fellowship were met; and
- the **impact** of the fellowship as a whole.

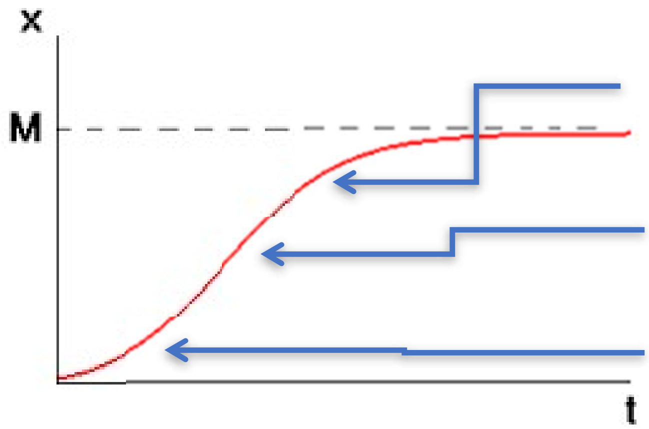
The *Impact Evaluation* (Owen, 2006) framework, with the following three features, aligned well with the objectives of the evaluation and the stance of the evaluators—that is:

- the **purpose** was learning/accountability;
- the **assumption** was that the need was to know what worked and why; and
- the **imperative** was the importance of transferability: that this program made a contribution to knowledge and practice.

From the principles of *Impact Evaluation*, the evaluators extracted the following measures:

Principle	*Measure*
• Maximise current, future impact	***Reach*** – How many staff were involved?
• Show achievement of outcomes	***Outcome*** – Did the activities deliver on their goals?
• Demonstrate quality innovation	***Quality*** – Was the fellowship program worthwhile? Were the innovations embedded?

The innovation cycle depicted in Figure 4 was also used to classify individual aspects of the fellowship program and assist in making recommendations for future work on the subject.



Category C: The individual aspect is of a form where an innovation, having been successfully piloted or successfully being used elsewhere, is adapted for large scale use

Category B: The individual aspect is of a form where an innovation, whether created or adopted from elsewhere by the fellowship team, is being piloted

Category A: The individual aspect is of a form where new innovations are being created, or where the innovation does not reach the tertiary science educators immediately as proposed in the grant

Figure 4. The three broad categories of projects extracted from the innovation cycle.

Table 2. The types of questions asked about each aspect of the fellowship.

What questions apply to a:				
Category A evaluation	Have they created the innovation?	How many staff are affected?	Are they at a stage to pilot the innovation?	
Category B evaluation	Have they piloted the innovation?	How many staff are affected?	Have they disseminated the idea to colleagues?	Are they ready for expansion?
Category C evaluation	Have they up scaled the innovation?	How many staff are affected?	Have they disseminated the idea to colleagues?	Is the innovation sustainable?

Data and methodology

Attendees of the main series of workshops were surveyed at the end of each workshop. These surveys were supplied to the evaluation team and were analysed in order to measure the *reach* and *quality* of the workshop series. This survey is subsequently referred to as the 'workshop survey'. Interviews with Professor Roy Tasker were also conducted to ascertain the *outcomes* of the goals of the fellowship and where the biggest challenges were faced.

In order to evaluate the *quality* of the workshops, a follow-up survey was designed by the evaluators and sent to the workshop attendees. In this component, questions were focused on how attitudes to the workshop material had changed over time. The questions also focused on how well material was retained and implemented, given that the follow-up survey was conducted 12–18 months after the workshop. This survey was also designed to measure *reach* by asking attendees about their engagement with colleagues regarding the workshop material. This survey is subsequently referred to as the 'workshop follow-up survey'.

A final survey was created by the evaluators and disseminated via the *Science and Mathematics network of university educators* (*SaMnet*); hence, it is subsequently referred to as the 'SaMnet survey'. This survey was also designed to measure the broader *reach* of the ideas championed by Professor Roy Tasker through the workshop series, into the wider educational community. It is also intended to indicate the *outcomes* of some of the broader goals of the project and the *quality* of the workshop by indicating actual usage of the workshop material in the wider educational community. The measures were refined, converging on the following interpretations.

Reach as a measure—How many educators were potentially involved with the fellowship? Involvement was through fellowship consultations, workshop and conference attendance, workshop attendees' conversations with colleagues, and website visits.

Outcomes as a measure—Were the individual goals of the fellowship achieved? Upon inspection of the data the evaluators developed criteria, such that each goal could be benchmarked against their proposed outcomes and what was reasonable for their category. This generated five sets of possible outcomes, shown in Table 3.

Table 3. Qualitative descriptions of sets of outcomes capturing whether individual goals of the fellowship have been met.

Exceeds Expectations	**The Fellowship has met all the criteria for this particular category, and has exceeded the project goals in a number of substantive ways.**
Yes	**The fellowship has met the majority of the criteria, and has met the majority of the fellowship goals as outlined in the NSTF application.**
Unsure	**The fellowship has met some of the criteria for this particular category, and either due to lack of reporting or detail, it is unsure whether the project has fully met its goal.**
No	**The fellowship has not met the criteria for this particular category, and there were no extenuating circumstances for the failure to meet the goal.**
Problems	**The fellowship has not met the criteria for this particular category, but there were issues outside the control of the fellowship that meant it could not meet the stated goal.**

Quality as a measure—How effectual had the individual goals of the fellowship been? For example, had they changed educator's attitudes? Had they been adopted by workshop attendees and/or a wider audience?

Findings

Reach as a measure—The first presentation of the workshop program was conducted as a pilot at ANU with 17 attendees from ANU and CSU. Attendance numbers for all the following workshops, and the associated workshop survey numbers, are shown in Table 4. A total of 127 educators were directly impacted by the workshops.

Table 4. Main workshop series attendance.

Workshops	Workshop Survey Reponses	Attendees
Canberra	15	17
Sydney	11	22
Melbourne	9	9
Perth	11	21
Brisbane	10	13
Adelaide	14	23
New Zealand	1	3
Sunshine Coast	N/A	19
Total	**71**	**127**

The result from Question 10 of the workshop follow-up survey is shown in Figure 5. There has been a considerable 'knock-on' effect, with more than 90% of the workshop attendees personally sharing ideas with their colleagues. This represents a considerable increase on the numbers of educators impacted by the workshops. The significance of this can been seen in the number of visits to the associated website, shown in Figure 6.

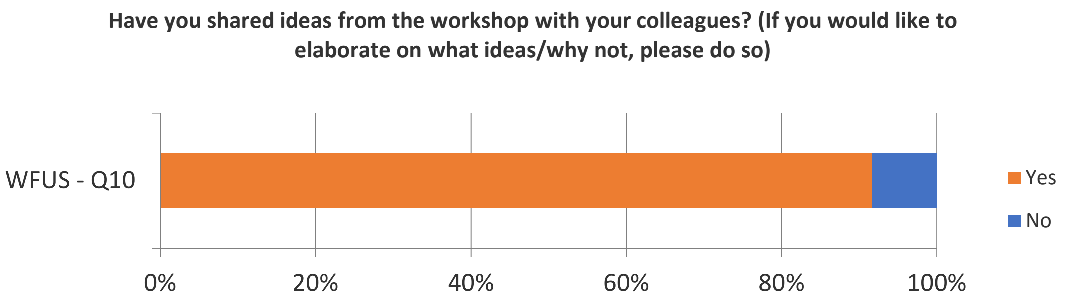


Figure 5. How many workshop attendees personally shared workshop material?

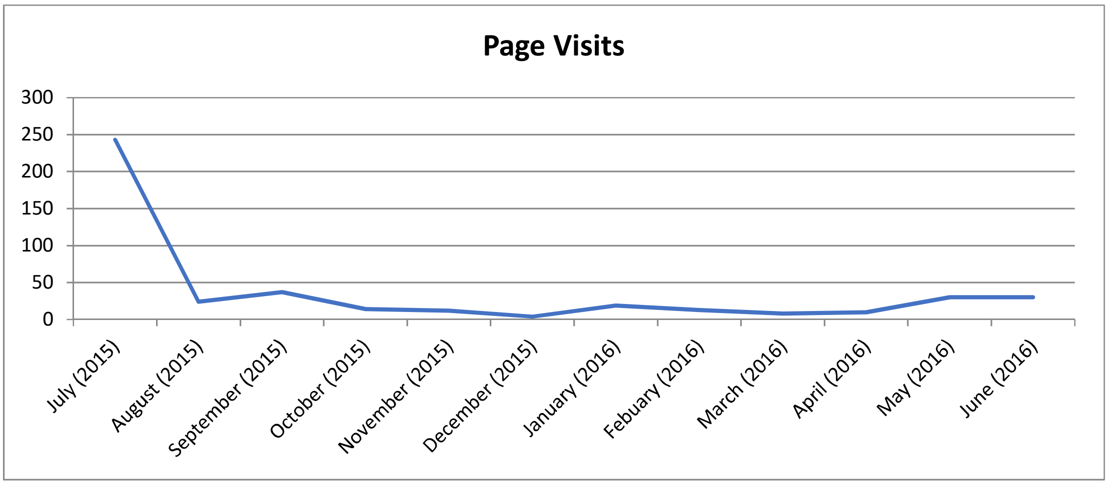


Figure 6. Number of website visits for the previous calendar year.

Website statistics were only available for the previous calendar year (July 2015 to July 2016). Unfortunately, the majority of the workshops were conducted in the first half of 2015. However, the last workshop (Sunshine Coast) was conducted in July 2015. A large spike in website visits (243 visits) can be seen in Figure 6 for this month, compared to an average of 18 visits per month in the subsequent year. The workshop follow-up survey also asked participants whether they had used the website. The result of this question is shown in Figure 7. Only 50% of attendees actually used the website. The combinations of these results indicate that a large proportion of website visitors were from colleagues of attendees. Given that the Sunshine Coast workshop represented 15% of attendees, it is estimated that over the course of the fellowship the website garnered approximately 1600 page visits.

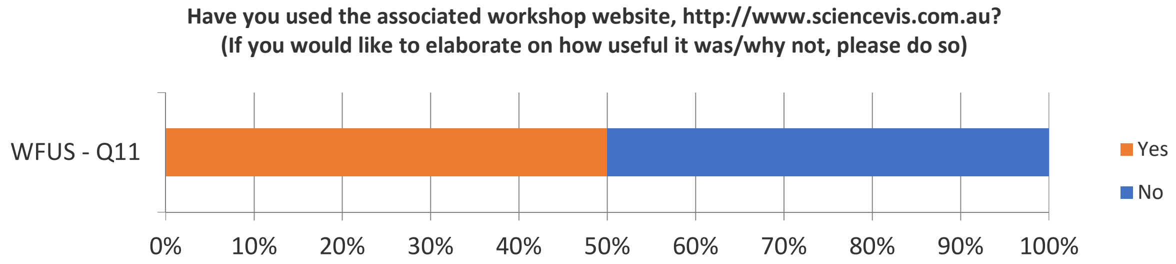


Figure 7. How many workshop attendees personally accessed the website?

Table 5. Estimated attendance of pre-workshop promotional conferences, post-workshop reporting conferences, and the national forum.

Promotional Conferences	
Collaborative Universities Biomedical Education Network (CUBEnet) Conference, ANU, December 2014	80
Australian Council of Deans of Science Teaching & Learning Conference, Brisbane, July 2014	70
Australian Institute of Physics National Congress, ANU, December 2014	65
Royal Australian Chemical Institute National Congress, Adelaide, December 2014	45
Post-workshop Conferences	
Gordon Research Conference on Visualisation in Science and Education, June 2015, Lewiston, ME, USA	160
Fellowship National Forum, UTS, July 2015	25
Total	**445**

A series of promotional presentations at national conferences were held before the workshop series, with estimated attendances shown in Table 5. After the workshop series, presentations were delivered at the *Gordon Research Conference on Chemistry Education Research and Practice* in the United States, and the Fellowship National Forum. In total, a further 445 educators were reached through these proceedings.

Outcomes: did the fellowship broadly achieve what it set out to do?

The original goals in the National Senior Teaching Fellowship (NSTF) nomination form for the fellowship were benchmarked against expectations and deliverables using the criteria in Table 4. Table 6 summarises the fellowship goals for the five sets of outcomes, as well as general comments on implementation.

Original goals

- **G1:** The fellowship workshops and resources will demonstrate some of the research findings on visual perceptions, including strategies for focusing attention on the key features in an external visualisation, minimising cognitive load and applying the cognitive learning model (Figure 2).
- **G2:** The fellowship program will aim to both *inform* and *embed* evidence-based visualisation pedagogy.
- **G3:** The fellowship will lead a nationwide discourse on the use of this approach to increase the engagement of students and teachers in science.
- **G4:** Six workshops will demonstrate how the cognitive learning model informs best practice in presenting external representations of models through visualisations, and explore strategies for learning and communicating internal representations by constructing visualisations.
- **G5:** The workshops will also support participants to develop their own visualisation of a threshold concept they find challenging to teach, for sharing on the fellowship web site. This approach aims to embed changes in practice in a concrete and valued way, providing practical deliverable outcomes for all university science educators.
- **G6:** Critical friends of the fellowship in the science discipline networks will be enlisted to identify possible participants within their institutions.
- **G7:** The workshop format and activities will be pilot-tested.
- **G8:** The fellowship will produce an active community of visualisation practice, sustained by the science discipline networks, developing new visualisation resources and strategies using evidence-informed best practice.
- **G9:** The fellowship web site will include a collection of external visualisations produced by workshop participants, plus exemplars available on the internet; a database of formative and summative assessment activities to elicit internal visualisations (e.g., drawing exercises) to reveal student mental models, and an updateable list of key references to the literature on the topics covered in the fellowship.
- **G10:** The fellowship program will be promoted at the key university science education forums and national conferences in the enabling science disciplines.
- **G11:** The fellowship web site will host an active blog, promoted with social media tools.
- **G12:** A national forum entitled *Best-Practice Visualisation for a Deep Understanding of Science* will be hosted to promote the fellowship in September 2015, as a satellite activity with Australian Conference on Science and Mathematics Education 2015.
- **G13:** An iterative cycle of evaluation, reflection, and innovation in the workshop activities and engagement in the web site, will be used to refine these activities.

Table 6. Summary of outcomes of workshop goals.

Goal	Outcome	Comments
G1	YES	We suggest more focus on strategies of implementation, in future work, for reasons described in detail in the *quality* section.
G2	YES	Survey results suggest that workshop material has been successfully communicated to and embedded in workshop attendees.
G3	UNSURE	There is insufficient data to quantify how much discourse has taken place due to the fellowship program.
G4	EXCEEDS	A total of eight workshops were conducted instead of the planned six. The workshops were well received by attendees. Introductory and follow-up workshops were conducted on the same day rather than over two consecutive days. This was done to boost attendee numbers as availability for two days was more restricted than just one day.
G5	EXCEEDS	
G6	YES	The strategy was followed and appears to have been successful, as workshop attendee numbers were adequate.
G7	YES	A pilot workshop was conducted. The location was changed from UWS to ANU.
G8	EXCEEDS	Survey and website data results suggest that workshop attendees extensively engaged their colleagues as an active community.
G9	YES	The website was constructed and used as planned.
G10	YES	Four conferences were attended for promotional presentations. However, ACSME was substituted with the CUBEnet conference.
G11	NO	The planned blog was constructed but not regularly updated. Engagement with attendees and promotion of the fellowship over social media was not implemented. Unlikely to have greatly impacted the overall effectiveness of the workshop, given that the material was effectively promoted through other means.
G12	YES	As planned, the National Forum was conducted as a satellite activity to Australian Conference on Science and Mathematics Education 2015.
G13	UNSURE	This is related to G11, in that the website was not used extensively to engage with the wider community. The iterative cycle of evaluation, reflection and innovation could have been more thoroughly documented.

Quality as a measure

Quality as a cohesive overview of the fellowship goals combines the elements of reach and outcomes as well as incorporating sustainability through the notion of whether the goal is embedded or not.

In order to determine how important the attendees perceived the major themes conveyed in the workshops to be, the same questions were asked in the workshop survey, the workshop follow-up survey and the SaMnet survey. The first question related to the importance of having students express their mental models in drawings; the results are shown in Figure 8. Attendees found this point to be very important, with 94% of attendees answering ‘yes’ to this question. This impression was embedded well with attendees, with 83% still answering ‘yes’, and none answering ‘no’ in the follow-up survey conducted 12–18 months after the workshop. This impression is considerably more positive than the impression represented in the SaMnet survey (‘yes’ = 50%), which was more representative of the wider educational community.

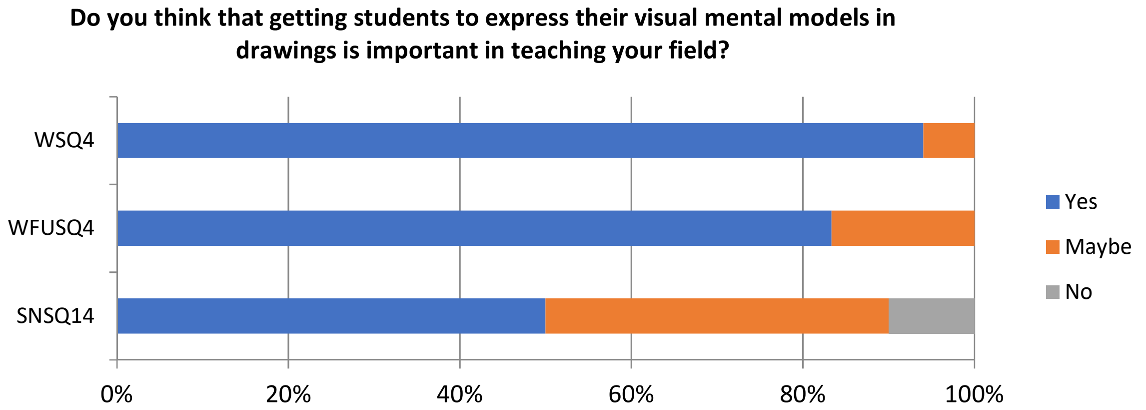


Figure 8. Survey responses relating to the importance of student mental models.

Although the importance of this point is significantly greater among workshop attendees, the proportion of workshop attendees who assess their students’ mental models (42%) was slightly lower than in the wider community (50%), as shown in Figure 9. The evaluators would suggest that future fellowship programs should focus on implementation strategies in order to build on the increased awareness, which was informed and embedded very effectively by the fellowship. We can consider this point in terms of the innovation cycle, depicted in Figure 4. The realisation of the importance of this point is in category A of the innovation cycle, among workshop attendees, while it is only in category B for the wider educational community. The practical adoption of this practice is in category B for both workshop attendees and the wider educational community.

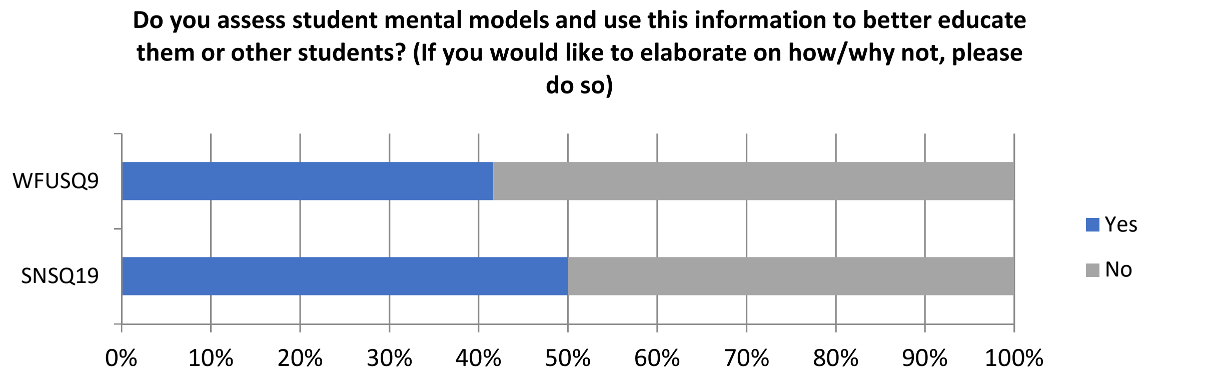


Figure 9. Survey responses relating to the practice of actually using student mental models.

The major pedagogical point introduced in the workshops concerned the challenge of the cognitive load of visualisation and the importance of minimising this load for students. The results on this aspect in the survey are shown in Figure 10. The number of attendees that found this point important (92%) was similar to that which found the expression of student mental models important (94%). However, this point is considered significantly more important by the wider SaMnet survey respondents (80% in Figure 10) than assessing their students' mental models (50% in Figure 9).

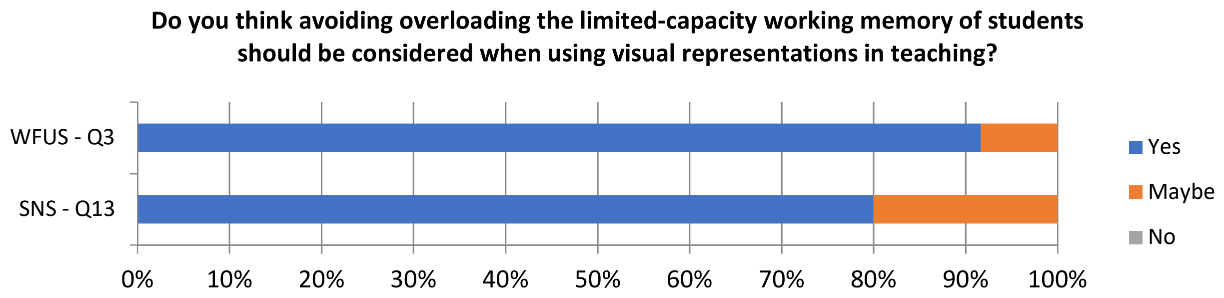


Figure 10. Survey responses relating to the practice of using student mental models.

The implementation of this important pedagogical recommendation in one's teaching is shown in Figure 11, by workshop attendees (68%) and the wider community (70%). This finding is important when the results shown in Figure 11 and Figure 12 are considered in terms of the innovation cycle. The importance of this point is in category A for both workshop attendees and the wider educational community, while the implementation of this point is in category B of the innovation cycle for both groups.

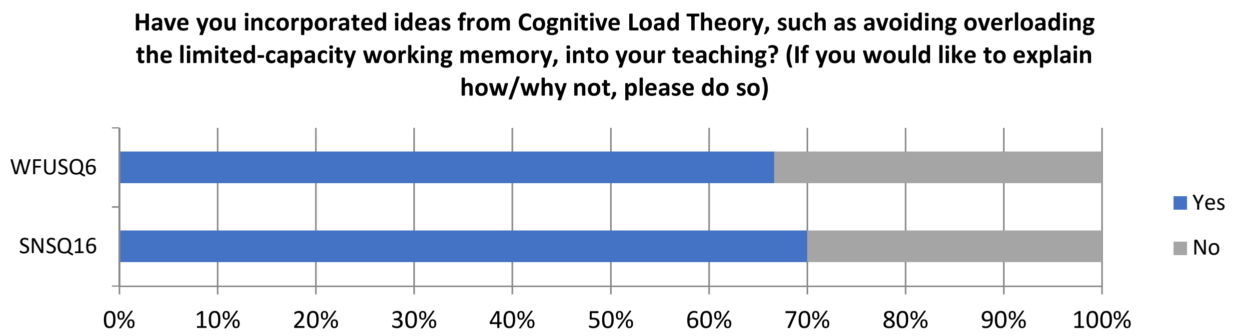


Figure 11. Survey responses relating to the practice of using CLT in teaching.

Interest in creating visualisations for their own students was gauged in the workshop survey, workshop follow-up survey and SaMnet survey. The results are shown in Figure 12. Immediate interest in producing visualisations for students after the workshop (84% = Yes, 7% = Maybe, 9% = No) was quite strong. However, this had dropped considerably by the time of the follow-up survey (58% = Yes, 42% = Maybe, 0% = No) and was closer to the attitudes of the wider educational community (60% = Yes, 20% = Maybe, 20% = No). This result indicated that the workshop was quite effective at *inspiring* educators, but that future Fellowships would benefit by placing more focus on implementation and support strategies for educators and faculties, in order to put CLT and other visualisation strategies into practice.

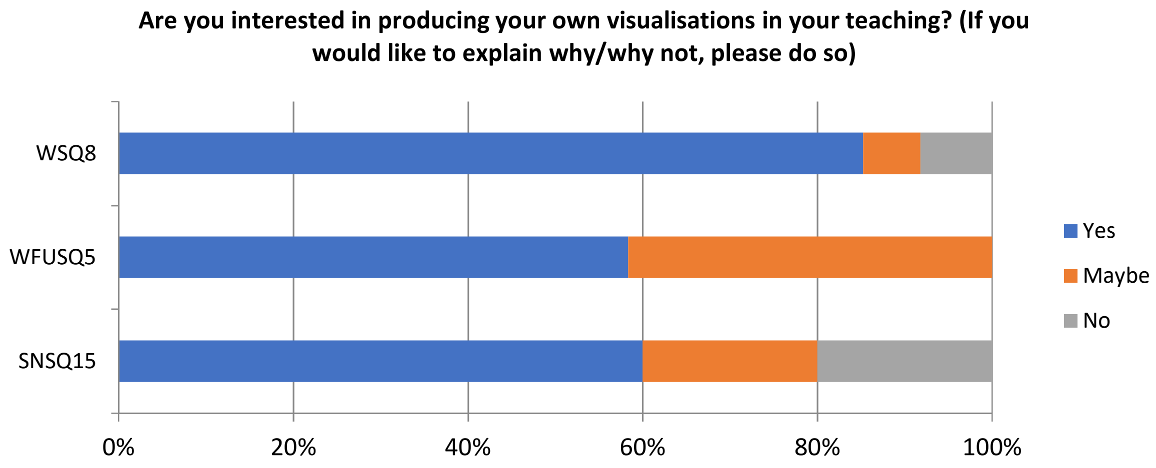


Figure 12. Interest in producing visualisations.

The actual implementation of producing visualisations, and the use of visualisations from other sources, is given in Figure 13 and Figure 14 respectively. Both rates are slightly higher for workshop attendees (75% and 92%) compared to the wider educational community, represented by the SaMnet survey (60% and 80%). When considering the implementation of producing visualisations in terms of the innovation cycle, it appears to be in transition from category B to category A for workshop attendees, and in category B for the wider educational community. The use of visualisation from other sources has been widely adopted and is represented by category A of the innovation cycle for both groups.

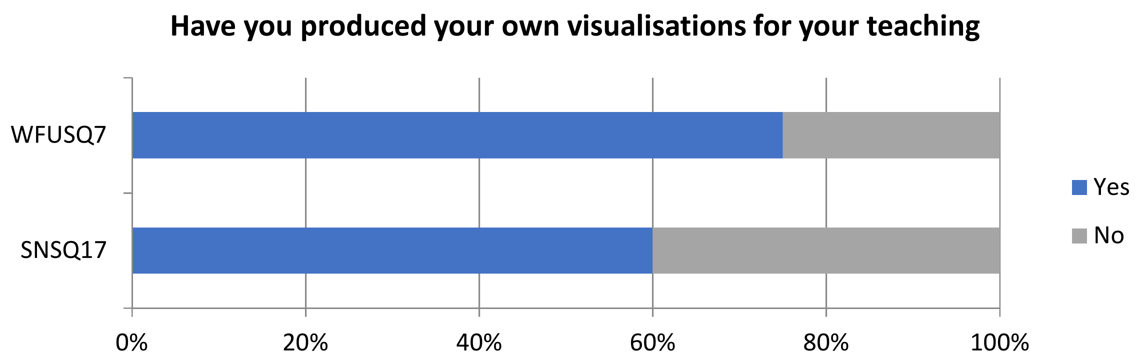


Figure 13. Actual production of visualisations.

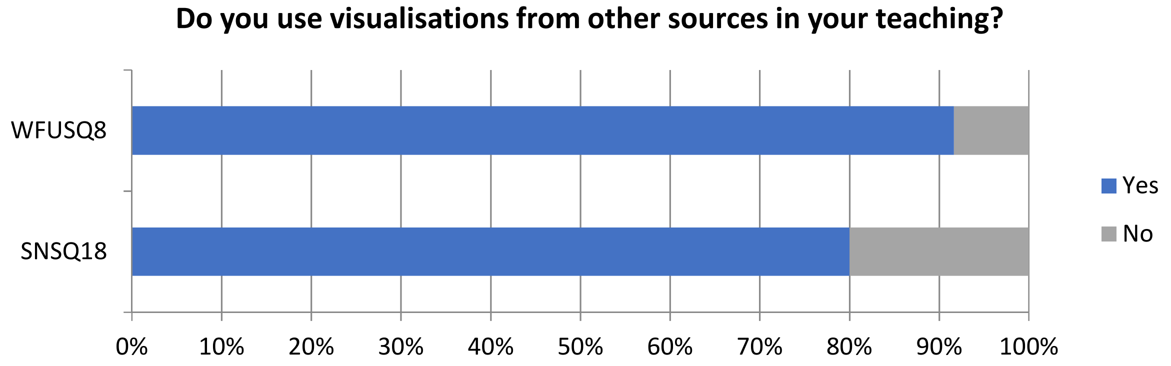


Figure 14. Usage of visualisation from other sources.

The SaMnet survey also questioned respondents on their background knowledge of CLT and the role that it plays in student learning; the results are summarised in Figure 15. Surprisingly, 45% of respondents to the SaMnet survey had also attended workshops by Prof Roy Tasker. For this reason it could be very likely that the differences between attitudes and practices of the wider educational community (that have not attended the workshop series) and attendees of the workshops are greater than the comparisons given in Figures 7–14 would suggest. This further implies that the impact of Prof Roy Tasker's fellowship was likely greater than Figures 5–11 would suggest.

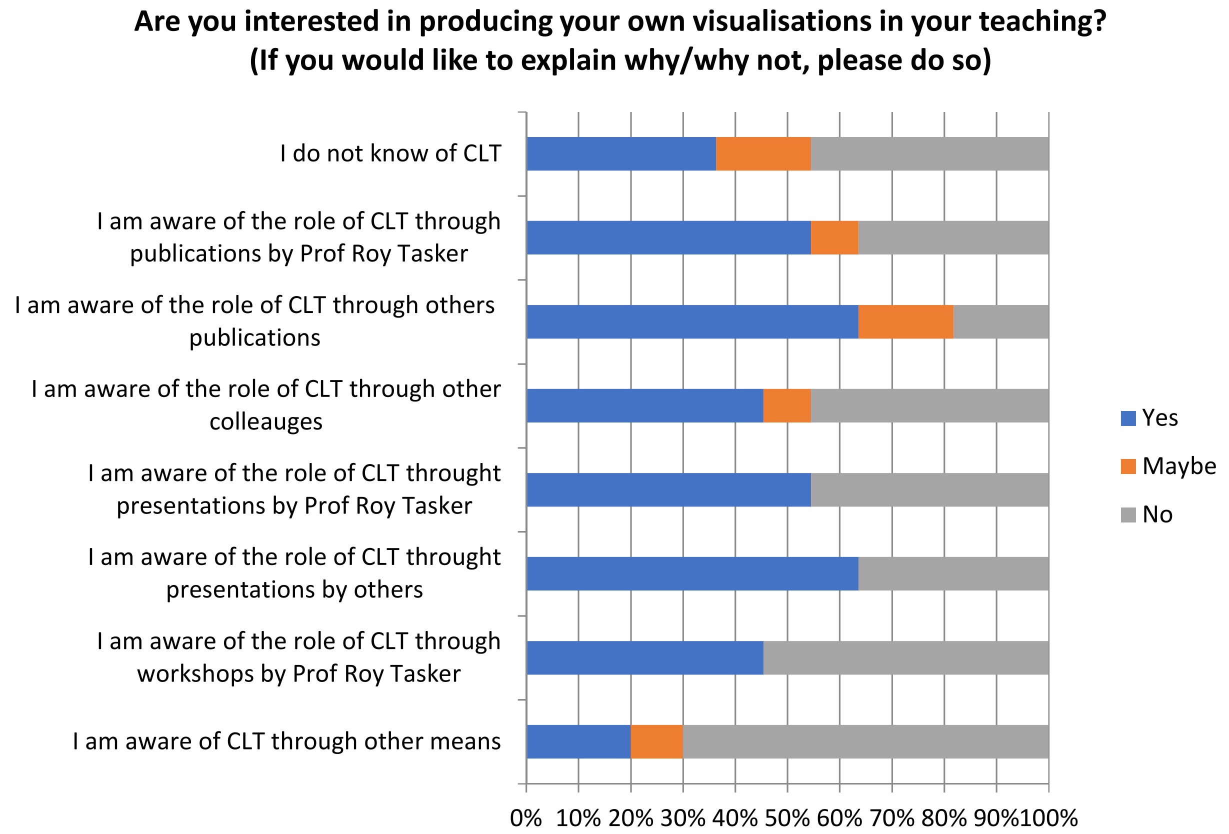


Figure 15. Sources of CLT background knowledge in SaMnet survey.

Figure 16 gives an overview of attendees' impressions of the workshop. A large majority of attendees found the workshop to be worth their time and energy (93% = Agree, 7% = Neutral, 0% = Disagree), and the majority also agreed that the length of the workshops was appropriate (87% = Agree, 9% = Neutral, 1% = Disagree). The worst overall response was to the group work activity (72% = Agree, 26% = Neutral, 1% = Disagree), which took place in the second half of the workshop. However, while this was the worst response, the majority of respondents still liked this portion of the workshops.

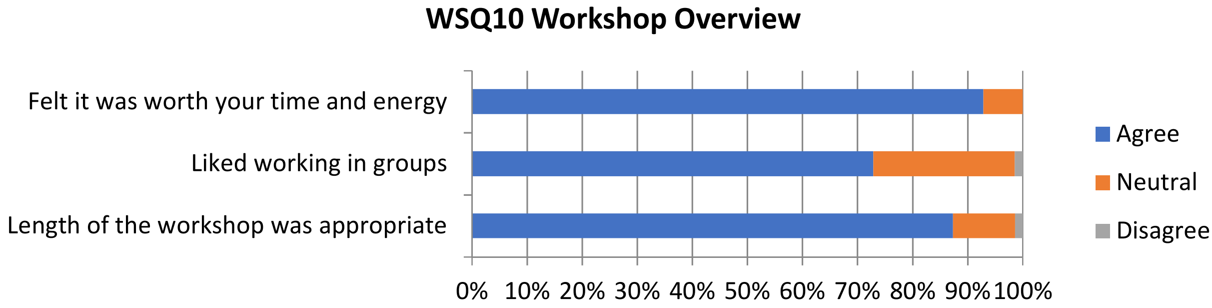


Figure 16. Survey responses relating to the practice of using student mental models.

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Appendix A

Certification by Deputy Vice-Chancellor (or equivalent)

I certify that all parts of the final report for this OLT grant provide an accurate representation of the implementation, impact and findings of the project, and that the report is of publishable quality.

Name: ....Date: ...23/11/18........

Professor Denise Kirkpatrick

Appendix B

Example of email promotion:

SUPPORTED BY

Australian Government | Office for Learning & Teaching

RESEARCH INTO PRACTICE

Evidence-informed, best practice visualisation
for a deeper understanding of science.

WORKSHOP

I am running a one-day workshop designed for science academics interested in strategically using all forms of visualisation in their teaching. You will see a practical, evidence-based cognitive learning model for processing audiovisual information, and its implications for embedding visualisation activities into a learning design. Individually, or in groups, you will apply these ideas to produce a learning design with your own visualisation (a complex diagram, an animation, or a simulation). Upon registration we will give you an access code to Odyssey molecular dynamics simulation software so you, and your students, can build your own animations and simulations in biology, chemistry and physics.

More details of the workshop activities are in the attached flyer, and the Fellowship website **ScienceVis.com.au** has a gallery of visualisation resources and research publications.

INCENTIVES

Other than the intellectual satisfaction and fulfilment of learning something new about something significant, you will be encouraged to upload your idea for a visualisation embedded in a learning design to the Fellowship website, and perhaps present it at the Fellowship National Forum in July.

For those interested, an enduring copy of the Odyssey College Instructor Edition software, valued at USD 600, will be awarded for the best learning design incorporating an activity using this simulation software.

WHEN
Friday 29 May from 10:00 am - 4:00 pm / with lunch provided

WHERE
Monash Conference Centre / Level 7, 30 Collins St, Melbourne

HOW TO REGISTER
To claim one of the eight places available for your institution please RSVP via the following link:

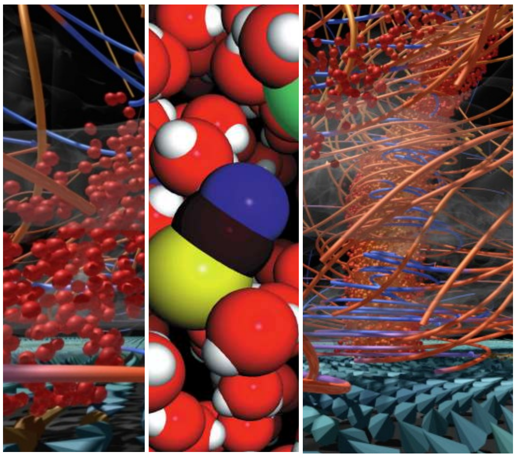
Appendix C

Promotion flyer:

SUPPORTED BY

Australian Government | Office for Learning & Teaching

RESEARCH INTO PRACTICE / Evidence-informed, best practice visualisation for a deeper understanding of science.



Professor Roy Tasker / OLT National Senior Teaching Fellow

This senior teaching fellowship will lead a national conversation on visualisation in university science - both its importance for learning complex concepts, and its best practice implementation in teaching science.
For more details go to: ***ScienceVis.com.au***

Workshop Synopsis

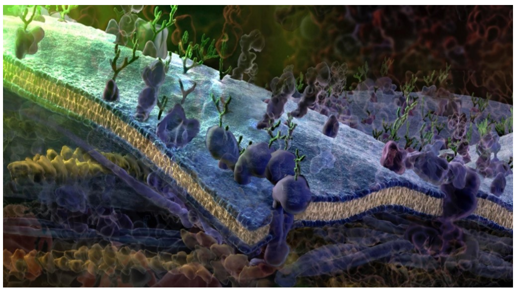
Workshops will build a community of practice to focus on using visualisation in all its forms for teaching science, informed by cognitive research on how we learn. Emphasis will be on helping students to develop mental models of imperceptible worlds and phenomena at cosmic, geological, cellular, molecular, and quantum levels, to understand the perceptible phenomena we experience.

WHY / Learning science involves imagination and modelling of invisible phenomena—such as molecular interactions, force fields, and energy changes—to explain observable phenomena—such as stickiness, magnetism, and heat transfer—and to create new insights. Visualisation of these imperceptible phenomena is the key to making meaning from the abstract scientific shorthand and language that too often alienate novices. Only when they have useful visual mental models of these invisible worlds can novices appreciate the enormous power of mathematics to generalise from the specific.

HOW / Using visualisation to communicate science should be informed by the latest cognitive science research on the factors determining how the brain perceives, processes, stores and retrieves audiovisual information.

Brief Bio

Roy Tasker is currently Professor of Chemistry Education at the University of Western Sydney, with primary teaching responsibilities in first-year chemistry, and research interests in how and what students learn using interactive multimedia visualization resources in his VisChem project (***vischem.com.au***). In 2011 he received The Prime Minister's Award for Australian University Teacher of the Year.



WORKSHOP OUTLINE

TIME	ACTIVITY	TOPIC & QUESTIONS ADDRESSED
10:00 / 10:30	Opening Discussion	Introduction • who has attended and why? • what are the workshop outcomes?
10:30 / 11:30	Presentation of a cognitive learning model as a theoretical foundation for using visualizations and its implications for best practice teaching for learning	An evidence-based learning model based on cognitive science research that offers explanations for: • why we lose attention so quickly in passive lectures? • how we can motivate students to engage with cognitively demanding content? • why 'scaffolding' and 'chunking' are so important? • what strategies lead to deep learning rather than surface learning?
	BRAIN BREAK	11:30 / 11:45
11:45 / 1:00	Group activity to embed participant visualisations in learning designs based on above model	Each participant designs a sequence of activities to build up to, embed, then build upon a visualisation (e.g., a graphic, animation, movie, or interactive simulation) to address a threshold concept , and discusses it in a group of non-specialists. Does the design • prime the perception filter to prepare the mind of the learner? • avoid overloading the working memory? • provide a variety of ways to link to prior knowledge?
	LUNCH	1:00 / 1:30
1:30 / 2:30	Local, national and international examples of innovative and effective visualizations	The Fellowship web site has a collection of stunning visualisations, with more added progressively. However, • what are the characteristics of a compelling and well-designed visualisation?
	BRAIN BREAK	2:30 / 2:45
2:45 / 3:45	Building new visualisations, and using student drawings to probe for deep understanding	There is a wide range of software tools for producing visualisations. • how easy is it to build animations and simulations? • why should science students be encouraged to draw, as well as calculate and write?
3:45 / 4:00	Wrap-up and making unrealistic promises to follow up	Upload your visualization learning design to the Fellowship web site, and consider presenting it to a wider audience at the Fellowship National Forum in July.

The workshop will also give you the 'student experience' of using response technology in a thoughtful manner to facilitate discussion, generate feedback, measure learning gains, and evaluate initiatives.

Support for this fellowship has been provided by the Australian Government Office for Learning and Teaching.
The views expressed in this activity do not necessarily reflect the views of the Australian Government Office for Learning and Teaching.

Appendix D

Evaluation Summary

Professor Manjula Sharma and **Dr Scott Cornish** at The University of Sydney utilised Impact Evaluation and the innovation cycle in order to produce the findings in Chapter 3. The evaluation process involved interactions with Prof Roy Tasker and multiple surveys of those involved with fellowship activities, and the wider educational community.

The following statements provide a summation of the evaluation.

I. Of the major goals set out in Prof Roy Tasker's NSTF Fellowship application, for which there is sufficient data to evaluate, 10 out of 11 were achieved or exceeded their stated outcomes, which is representative of the overall success of the fellowship.

II. The main focus of the fellowship program was the workshop series. The number of planned workshops was exceeded by 25% and the workshops were well received by attendees. Retention of workshop ideas was high, while implementation of ideas was in some cases not larger than within the wider educational community.

III. Uptake of the main ideas demonstrated in the workshops are in the later stages of the innovation cycle, with the recognition of the idea's importance generally in category A of the innovation cycle, and implementation of these ideas into teaching practice generally in category B.

IV. The main suggestion from the evaluators for future fellowship programs would be to boost the uptake of workshop ideas into educators' personal teaching strategies. This could have been achieved by the implementation of the stated goal of wider community engagement online through social media and an active blog. This was the only goal of the fellowship that was not successfully implemented. However, in the evaluators' opinion, this would not be so significant to the outcome. This is because these online methods are generally most effective at raising awareness and informing, which were already achieved very well by other aspects of the fellowship program.

V. The possibility of greatly impacting educators' teaching strategies is highly aspirational and difficult to achieve. In this case there are limitations in the structure of the fellowship, being workshop-based to a wide audience of voluntary participants. In order to achieve more impact into changing the personal teaching habits of educators, the evaluators suggest future fellowship programs more deeply engage entire faculty-wide groups. This is a promising strategy, given the success of this fellowship in embedding the importance of these teaching practices in the individual faculty members who participated.
