Chapter 1

Development of Scaffolded Online Modules To Support Self-Regulated Learning in Chemistry Concepts

Gwendolyn A. Lawrie,*,[1] Madeleine Schultz,[2] Chantal H. Bailey,[3] Md. Abdullah Al Mamun,[4] Aaron S. Micallef,[5] Mark Williams,[6] and Anthony H. Wright[7]

[1]School of Chemistry & Molecular Biosciences, The University of Queensland, St Lucia, QLD 4072, Australia
[2]School of Chemistry, Physics and Mechanical Engineering, Queensland University of Technology, Brisbane, QLD 4001, Australia
[3]School of Chemistry & Molecular Biosciences, The University of Queensland, St Lucia, QLD 4072, Australia
[4]School of Education, The University of Queensland, St Lucia, QLD 4072, Australia
[5]School of Chemistry, Physics and Mechanical Engineering, Queensland University of Technology, Brisbane, QLD 4001, Australia
[6]School of Science & Health, Western Sydney University, Penrith, 2751 NSW, Australia
[7]School of Education, The University of Queensland, St Lucia, QLD 4072, Australia
***E-mail: g.lawrie@uq.edu.au**

Teachers rely on representations, simulations and animations in their classrooms to explore and expand students' conceptual understanding in chemistry. Researchers adopt the same visualization tools to investigate student understanding and to support their communication of the outcomes of their research studies. In the past decade, many carefully designed web-based resources including sophisticated simulations and animations have been developed and are accessible online for teachers to engage students in guided and inquiry activities. In spite of decades of research on student difficulties with conceptual understanding, there are few examples of modules

Schultz et al.; Technology and Assessment Strategies for Improving Student Learning in Chemistry
ACS Symposium Series; American Chemical Society: Washington, DC, 2016.

incorporating these online resources designed to improve students' understanding of concepts that underpin learning in tertiary chemistry. In this project, the design and delivery of five online modules covering fundamental chemistry concepts has been explored, informed by research literature in the areas of scaffolding and visual representations. The aim was to encourage students to engage in self-regulated exploration of these modules, initiated by the provision of formative feedback through a diagnostic instrument. Two separate mechanisms for delivering online modules, both integrating existing web-based resources, were trialed and evaluated in terms of student engagement and perceptions.

Introduction

Multimodal representations of models, processes and concepts at the macroscopic, submicroscopic and symbolic levels are integral to learning chemistry. To engage with these representations, students must develop skills in translation between the various forms, as well as assigning meaning to them. Many excellent online resources for teaching chemistry concepts using these representations are readily accessible including interactive simulations such as Molecular Workbench (*1*, *2*) and PhET (*3*, *4*). These sophisticated resources are designed as tools that teachers can integrate into their teaching contexts with multiple shared lesson plans and exemplars for practice on the respective websites. The tools have also now been applied in research studies seeking to understand whether online dynamic visualizations support student learning and related factors (*5–8*).

While teachers adopt these resources to support their students in the construction of understanding (*9*), there are few studies that report the development of interventions aiming to correct misconceptions (*10–12*). Improving the understanding of basic chemistry concepts is somewhat of a holy grail in chemistry education. Extensive research over many decades shows that alternative conceptions are often established in the early years (*13–15*) and can be very persistent (*16*, *17*). Instruments profiling misconceptions in many different sub discipline areas of chemistry have been published (*18–21*). Remediation of misconceptions may require existing understandings to be challenged through cognitive conflict and then rebuilt (*22–25*). However, if a consistent world view does not exist in the student, there may be a lack of conception rather than a misconception and this should be easier to remedy (*17*, *26*).

In this project, we aimed to design and implement self-regulated online learning modules that support the construction of conceptual understanding in chemistry within five topics. The stand-alone modules were developed to be suitable for independent use by incoming tertiary students to enable them to direct their own learning (*27*) and remediate missing and missed conceptions (*28*). A review of the literature indicates that the following components should be incorporated in the design (*29–31*):

- Scaffolding (*32*);
- Representations (*33*); and
- Formative feedback (*34*).

Monitoring factors that affect cognitive load is also important in the design phase in order to avoid unnecessary overload on users (*35*, *36*).

A critical issue in development of the modules was the level of scaffolding required for inquiry learning to be effective in the context of the simulations, animations and representations. The concept of scaffolding was developed in the context of teacher- (or parent-) student interactions, and original definitions require it to be dynamic, fading as students become more competent (*37*). Several authors have argued that without additional one-on-one scaffolding provided by a teacher, computer-based scaffolding is ineffective (*38*, *39*).

> *It remains an open question as to whether computer-based scaffolds need to exhibit dynamic assessment to be termed scaffolds. Within the scaffolding framework, dynamic assessment is intended to help the teacher provide just the right amount of support at just the right time to students. Several potential dangers of not dynamically adjusting scaffolding support have been noted. First, some authors caution that by failing to dynamically adjust support, designers may fail to promote students' ability to independently perform the supported task... Second, some authors note that failure to dynamically assess student ability may cause cognitive overload on the part of students who can already accomplish portions of the task effectively...* (reference (*37*) p. 513)

However, scaffolding strategies to support online inquiry learning have been proposed (*40*, *41*).

> *These guidelines include (a) explicitly describing the structure of online inquiry tasks via visual representations so learners can better understand tasks they may only naively understand; (b) incorporating planning tools so that learners can think about their tasks in advance and plan their online inquiry more often; (c) making the online inquiry process, the working history through that process, and information common to multiple activities explicit to learners so they can monitor and regulate their work; and (d) providing reflection support through prompts to help learners see what they should reflect on and articulate throughout their online inquiry.* (ref. (*40*), p. 242)

These approaches allow students to effectively self-scaffold by skipping repetition when they are confident that they understand a section. An example of a computer tutorial that uses scaffolding effectively in teaching students organic chemistry has been published (*42*).

Multimedia (*33*) and animations (*43*) have been shown to assist students as they begin to transition between the macroscopic, sub-microscopic and symbolic representations used in chemistry (*44*). Tasker has developed a suite of materials known as VisChem that has been recognized as best practice in learning design to enable students to visualize chemistry using all three representations (*45–47*). The VisChem methodology of representing molecules graphically was adopted throughout the project.

Concept check questions were included regularly within the modules to assist students to monitor their learning through immediate formative feedback (*34*). The importance of immediate feedback has been emphasized as critical to improving understanding (*29*).

A model for IT continuance has been established that integrates factors likely to lead people to use technology again after they have tried it (*48*). Designing and building a website is time consuming and expensive so it is critical to be aware of factors that are likely to lead to its adoption and continuance. Awareness of these factors informed our approach as the project evolved.

This project formed part of a broader project that began by profiling the conceptions of incoming tertiary students at five universities in Australia (*49*) with the aim of providing formative feedback and remediating misconceptions. The methodology of the project was to use student responses to clusters of questions on chemistry topics covering multiple concepts to direct them to online activities tailored to their specific difficulties. Having established an instrument for this purpose (*50*) the present manuscript describes the process of development and implementation of the online modules, and outcomes from the first two years of its use. Affordances and limitations of the different strategies are described to provide recommendations for practice.

Design Methodology

Design of the online modules was guided by the need to deliver tailored activities appropriate for each student's current level of understanding. Students were directed to suitable activities according to the combination of responses that they selected in the ordered multiple-choice items (*51*, *52*) of the diagnostic instrument (*50*). Thus, not only whether they were correct, but also their choice of distractors was relevant to the selection of suitable activities. In order to cover the range of student understanding in large, diverse first year chemistry cohorts, four categories were developed with different objectives as shown in Table 1.

Further feedback provided after students' initial interactions with the online modules moved them to other categories and towards improved conceptual understanding. This iterative cycle (Figure 1) was designed to support students in the transition into tertiary chemistry studies (*27*, *49*).

A storyboard was established for each of the five topics to elaborate the combination of activities, instructions and elements that would be incorporated for students within each category. Within each topic covered in the diagnostic instrument, multiple concepts are required for understanding, so the activities were organized around the headings in Table 2. These headings were not determined in advanced but grew organically from an analysis of distractor choice in the instrument and misconceptions common to many students. Figure 2 shows a screenshot of part of the storyboard for one of the topics.

Table 1. Categories for the structure of online activities

Exercise category	*Students level of understanding*	*Online activities*
Concept Builder	Student's responses indicate negligible understanding of concept.	Introduce student to the concepts through foundation ideas.
Concept Fix	Student possesses a significant alternate conception.	Introduce cognitive dissonance to challenge student's conceptions.
Concept Shift	Student possesses a minor alternate conception.	Present student with an alternative model to clarify concept.
Concept Quest	Student possesses well-formed conceptions.	Provide student with the opportunity to apply and extend their understanding.

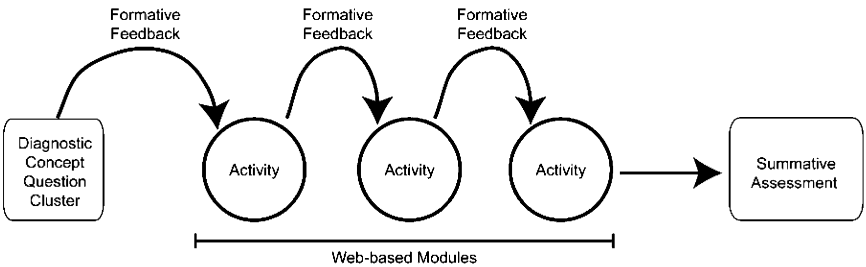

Figure 1. Iterative cycle of feedback and activities. (Adapted from Ref. (49) under Commons Attribution Licence (CC-BY). Copyright 2013).

In addition to careful storyboarding, the design of each module required careful consideration of the learning objects that were sourced. We integrated activities from existing high quality online resources suitable for the topics that we addressed (*2*, *3*, *46*). YouTube videos were included where directly relevant. Best practice in representing chemical processes, particularly in aqueous solutions, within graphics and animations from the VisChem project (*45–47*) was adopted. The different visualization tools that embedded in the modules can be classified in the following categories (*53*):

- simulation - an interactive dynamic representation that is pictorial;
- animation - a dynamic representation that is pictorial;
- video - a dynamic visualization that is photorealistic;
- static diagram - a graphical representation that relies on some abstraction.

Table 2. List of topics and subtopics covered by the diagnostic instrument item clusters and online modules

Topic	***Subtopics / concepts***
Phase change	intermolecular interactions molecular water states of matter
Conservation of matter	balancing equations fate of matter reaction stoichiometry
Aqueous solutions	dissolution speciation dissolving salts and solubility dissolving salt proportional reasoning
Heat and energy	heat transfer thermal expansion making bonds energy and reactions
Chemical equilibria	chemical equilibria dynamic equilibrium Le Châtelier's principle saturated solutions

Figure 2. Part of storyboard overview for the Phase Change module activities. (Reproduced with permissions from Refs. (2), (3), and (46). Copyright 2013 and 2016).

It has been shown that including narration with visual presentation reduces cognitive load and may assist student understanding (*54*).

In our teaching practice we have noticed that many students need some demonstration of how to use simulations in order to understand what they do and how they can be controlled and explored. We wanted to guide students to particular activities and in some cases restrict the complexity of the simulations to focus attention on a particular phenomenon. Thus tutorials were created where simulations were implemented in the modules in both structured and explorative manners, so that students received different levels of guidance in how to interact with the simulations. For example, in the module on chemical equilibrium, some PhET simulations were carried out by the researchers and included in the modules as animations with embedded instructions to assist students to later carry out the simulation as envisioned for the activity. A screen shot of such an animation tutorial is shown in Figure 3.

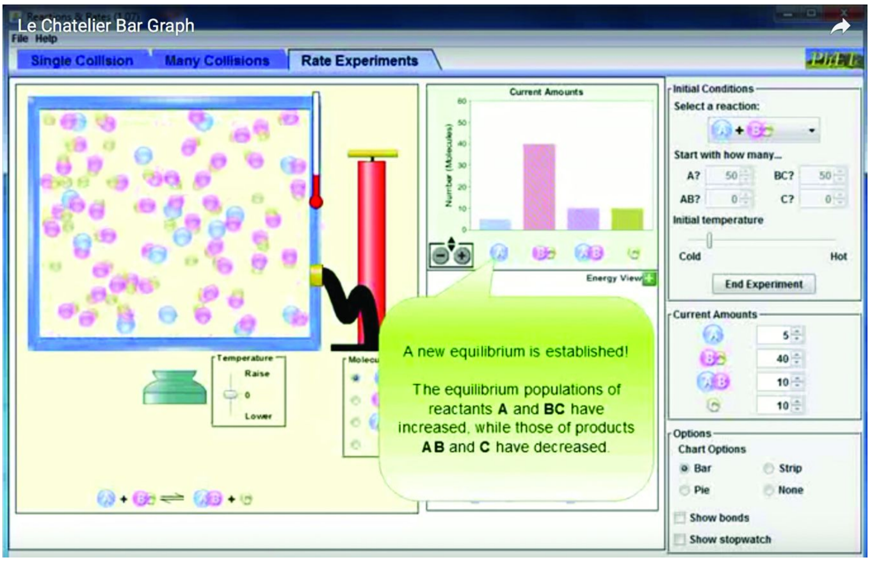

Figure 3. Screen shot from a video scaffolding students' use of a PhET simulation in ChemBytes Chemical Equilibrium module highlighting important interactive features. (Reproduced from Ref. (3) under Commons Attribution Licence (CC-BY). Copyright 2016. https://shire.science.uq.edu.au/chembytes/Index.html#/Home/Main).

Based on their experiences in implementing these simulations in their classrooms, project team members decided that guided instruction is more useful than open investigation when using sophisticated simulations with many variables. Another form of scaffolding is posing questions to direct student interaction with the simulation. This initiates students' exploration and later on guides them to open inquiry.

A website was built around the storyboard for each module with progression through the categories listed in Table 1 and incorporating the different visualization tools. The modules were designed to be completed asynchronously (in self-directed manner) or synchronously as part of classroom activities as a form of 'blended' learning.

In the first iteration, known as ReSOLv (illustrated by element symbols), students were sent an individual password to access the website (detailed in evaluation methodology below) by email. This email also included their score on the diagnostic instrument and the class performance for each question as a percentage of students who answered correctly. Based on their performance in the diagnostic instrument students were directed to a specific starting point in one of the categories listed in Table 1. Analytics were used to track student engagement and progress through the various web pages and activities. It should be noted that engagement with the website was not required as part of any teaching activities or assessment at any of the participating universities in semester 1, 2013.

In this iteration of the website, a student's progress through the activities was dependent on their entry level. This was structured through a flowchart for each module. An example is shown in Figure 4. The path included concept check questions for immediate feedback after each activity.

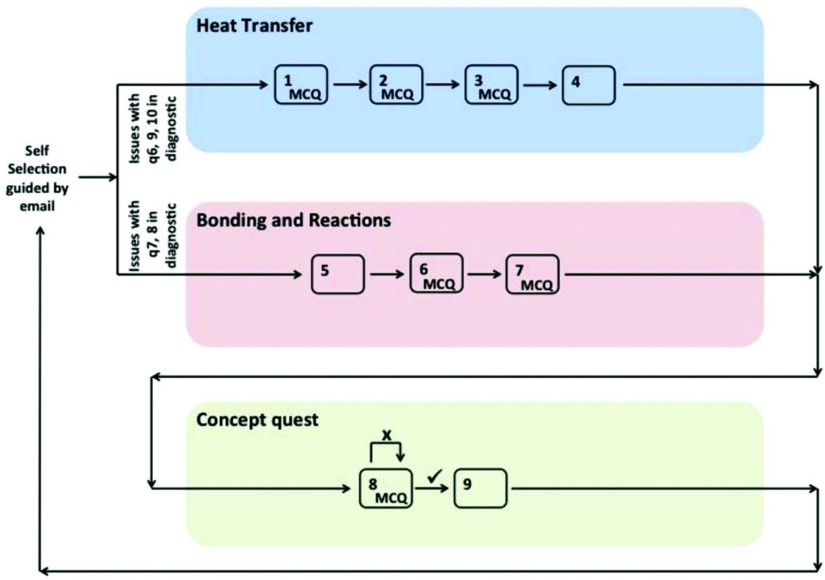

Figure 4. Flowchart for the structure of the ReSOLv website showing the scaffolding involved in students' progress through the Heat and Energy module.

This structure led to low rates of usage by students and so an open website was developed. In particular, the flowchart forces the students' order of engagement with the material and was abandoned.

The second platform trialed was ChemBytes, a series of bespoke web pages. The design of these web pages was inspired by the Five Minute Physics project from the University of Queensland (*55*, *56*) which is designed to engage students in concepts and topics in physics courses as part of a flipped classroom delivery. The features that appealed to the project team included the app-like icons for different topics, the 'How am I doing' check questions and the 'Summing up' reprises. We adopted the scaffolding approached advocated by Quintana for online learning (*40*), explicitly describing the tasks and allowing students to plan, monitor and reflect on their progress. A pilot platform elicited insight into student engagement and informed additional desirable design features such as additional white space, less text, more images (macroscopic and submicroscopic representations) and the options for students to interact with animations and simulations. The design minimized unnecessary cognitive load (*36*) and explicitly made connections between representations as recommended (*33*). Figure 5 shows a screenshot of a page within ChemBytes to illustrate the look and feel that was achieved. The ChemBytes pages can be accessed from the project website http://www.iammicproject.com.

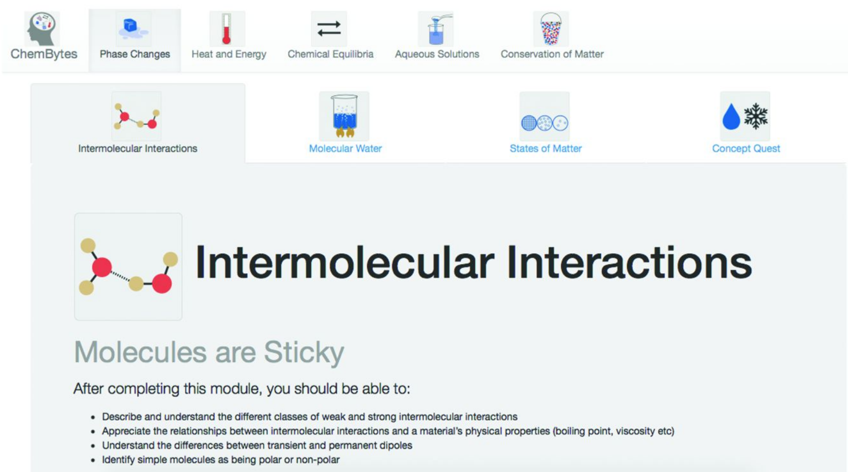

Figure 5. Screenshot of a landing page within the topic of Phase Change in ChemBytes. (Reproduced with permissions from: https://shire.science.uq.edu.au/chembytes/Index.html#/Home/Main)

Students were directed to the ChemBytes web pages through URLs embedded within their institutional LMS. Google Analytics was enabled to collect data with regard to student engagement with the web pages, including the times when students accessed the site, the average time spent on the site, location from which they accessed the site, devices they used and browsers. The modules were recommended by the instructors in general chemistry courses at two institutions in semester 1, 2014 as part of students' self-directed studies.

Evaluation Methodology

This study is a subcomponent of a larger project which has investigated the provision of formative feedback in relation to students conceptions in chemistry in order to direct them towards online learning modules. The larger study implemented the Learning Environment, Learning Process and Learning Outcomes (LEPO) evaluation framework (*57*) to collect and analyse data. This evaluation was supported by ethical clearance secured in all five participating universities.

Students who participated in the current study were first-year general chemistry students who were enrolled across five Australian universities, situated in three Australian states. They were enrolled in a diverse set of programs of study including, but not limited to, engineering, biotechnology, materials science, agricultural science, medicine, pharmacy, dentistry, biomedical science and health sciences.

Student activity in the ReSOLv web platform was monitored through web analytics for individual students. Students were initially sent a login password as part of their feedback from a diagnostic concept diagnostic instrument (*50*).

ChemBytes was designed to replace ReSOLv after early evaluation of ReSOLv revealed its low uptake so the two platforms were subjected to a parallel comparison. The evaluation of ChemBytes included analytics data collected through the website and statistics available through the learning management systems, Blackboard (Bb) and Moodle.

Participant recruitment was through email invitation sent to the whole class enrolment and informed consent, with a provision to opt out of the study at any time, for both the online questionnaires and focus group interviews. The online questionnaire was delivered at the end of semester 1 in only one university where the online modules were provided through Bb as optional study resources prior to completion of a summative quiz. The questionnaire contained several quantitative scales exploring the learning environment, student motivation and the data for only one item presented here. As part of a cluster of items evaluating learning in activities in the course, the following question was asked: How much did completing the CROM online modules help your learning? Scale answer options included ‘No help’, ‘A little help’, ‘moderate help’, ‘much help’ and ‘great help’.

Several open questions in the online questionnaire explored students’ perceptions in relation to the online modules delivered through Chembytes and other online resources. While this questionnaire captured a range of data related to multiple course activities, the specific open response question that was of interest to this study was framed to ilicit a range of responses: ‘Many of the [modules] used interactive visualizations / animations / videos of molecular level processes. Which of these were the most useful for helping you build your understanding in chemistry?’ 1536 students were enrolled in the course and were invited to complete the online questionnaire through an email sent through Bb, and 1003 students responded to this question. This open response data was thematically coded by an inductive process in NVivo to identify emergent themes that were then used as categories. Two separate focus group interviews were conducted to explore the accessibility and barriers to the use of the two different platforms for delivery of the modules. Interview 1 involved 7 participants and interview 2 involved 8 participants (N = 15 total).

Results and Discussion

Three key elements were incorporated into the design of the online modules: scaffolding, visual representations and feedback. During the original online module design, the project team intended that students would be required to login to the online activities so that their progress could be guided and monitored. However, several disadvantages were encountered in the pilot of the activities on the ReSOLv website which indicated that student entry and progression in the modules was over-scaffolded. Firstly, generating and distributing individual login information for thousands of students enrolled in multiple universities became complex and time consuming. Secondly, students were not observed to engage significantly with the system, presumably partly because of the requirement to login with details that were sent to them rather than self-initiated. 1654 students enrolled in four separate Australian universities were sent a login URL and password to access the ReSOLv modules. 141 (8.5%) students logged into ReSOLv and 86 students did not continue despite 5 of these logging in on two occasions. Of the students that did complete activities, it is not possible to discriminate the 3.3% students by institution because 19 of this group supplied a personal contact email (@gmail, @hotmail, @live, @yahoo etc) rather than their student account.

The ReSOLv website had highly structured pathways guiding students through the activities (Figure 4). Progress was scaffolded and there was limited opportunity for students to iterate activities at will. In contrast, ChemBytes did not require a dedicated login and students were provided access through a hyperlink to a website delivered through the learning management system. Each instructor was able to deliver the online modules to fit their context and to align with their curriculum's learning progressions. Figure 6 presents a schematic flow chart for how students move through a module comparing ReSOLv with ChemBytes.

The adoption of a website to deliver online modules reduces the opportunities to track student engagement with learning objects as individual 'clicks' made by a single student are no longer accessible. Ideally, the usability of ChemBytes is best explored through observation and interviews with a small number of students as they engage with the learning activities. In this study, we were evaluating over a thousand students and evaluation is restricted to Google Analytics and students self-reported perceptions and feedback in online questionnaires and focus groups.

Google Analytics data collected during one semester for the use of ChemBytes over four of the modules is presented in Table 3. It can be seen that although the number of users drops slightly as the semester progresses, the average time per session remains above 10 minutes and around half of the approximately 1500 students in this group used each module of ChemBytes.

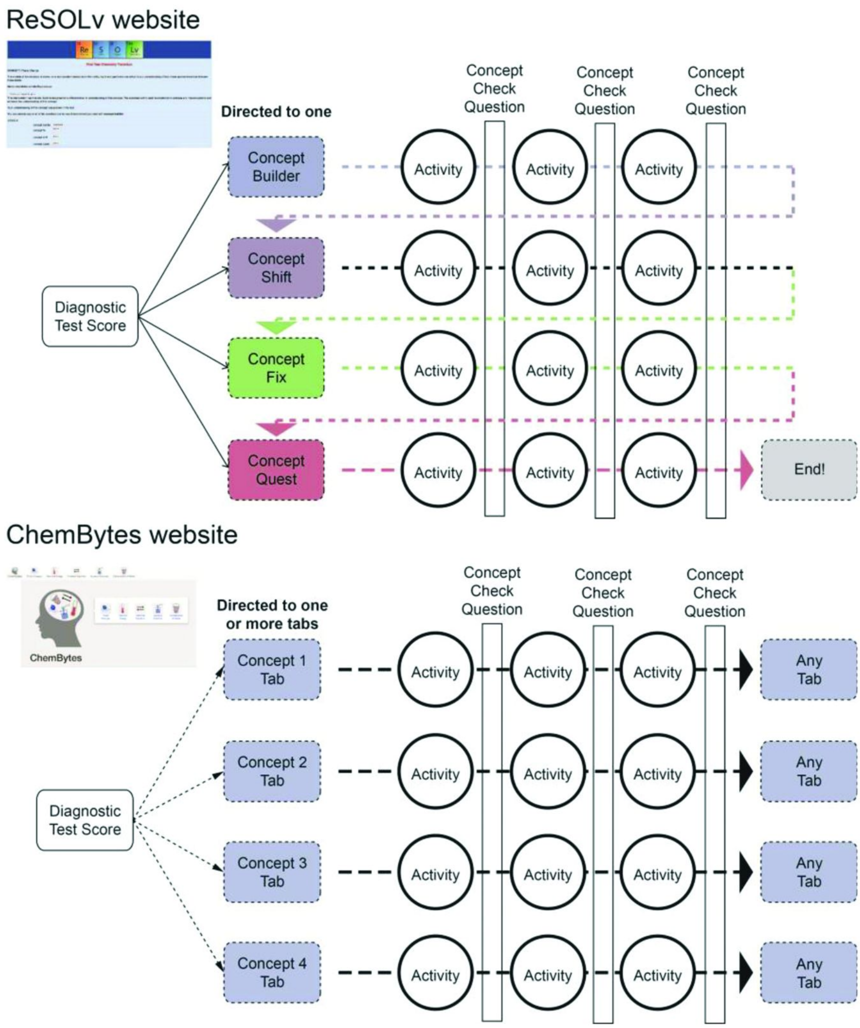

Figure 6. Flow charts showing typical student progress through ReSOLv (upper chart) compared with ChemBytes (lower chart) modules. (Reproduced with permissions from: https://uwssites.uws.edu.au/equiz/iammic/login.php and https://shire.science.uq.edu.au/chembytes/Index.html#/Home/Main).

A limitation of Google Analytics in the evaluation of student activity on website pages is that it cannot supply individual information in regard to the identity of users so it was not possible to monitor individual students. To overcome this, identifying information could be collected by embedding a text field directly in the web page; however, our aim was to encourage self-regulation in our students through their use of these study resources. The project team believed that maintaining their anonymity would better support their independent exploration of these web resources. Google Analytics does provide useful information in terms of demographic information for all users including: gender, location, device, operating system and browser.

In alignment with the IT continuance model, although the core content of the modules did not change substantially, moving from the ReSOLv website to ChemBytes improved multiple factors including "facilitating conditions" (no login required) and "satisfaction" (faster) that are likely to lead to continuance behavior. Barriers to access to ReSOLv raised by students in interviews included login difficulties, Java/Flash problems and problems using the site on mobile devices; all of these fall under facilitating conditions for continuance (*48*). While learning online, students prefer all content to be run in the same window. During interviews, many students reported that the PhET simulation (Java applet) opened in a different window and this appeared to have impacted on their engagement.

Table 3. ChemBytes Google Analytics data for use of ChemBytes, semester 1, 2014

Module	*Number of Sessions*	*Number of Users*	*Page Views*	*Average time*
Phase Change	1441	1092	5011	11 min 17 sec
Heat & Energy	1361	999	5449	12 min 25 sec
Equilibrium	1108	832	4290	15 min 22 sec
Aqueous Solutions	785	653	2616	10 min 21 sec

One of the design elements was the deliberate incorporation of representations to support learning. Inductive thematic coding of student responses to the survey asking which visualization mode was most useful distilled four major themes:

- 'seeing' molecules;
- explanations (audiovisual);
- interactive; and
- "visualizations did not help".

Figure 7 provides the breakdown of responses into each category. It should be noted that students were not provided with definitions for each category and so there was substantial crossover and substitution of terminology in their responses, in particular between animation and video. A total of 1003 enrolled students responded and consented to participate in the study (65% completion rate) to the survey. While there was not a specific question that asked these students whether they had used ChemBytes, a five point quantitative scale item indicated that 3.8% students had found the online activities were of 'no help' in their learning and 67.4% found them to be 'much help' or 'great help'. While there is no doubt that students enjoy multimodal representations, students identified with 'seeing' molecular level structures and processes to the greatest extent.

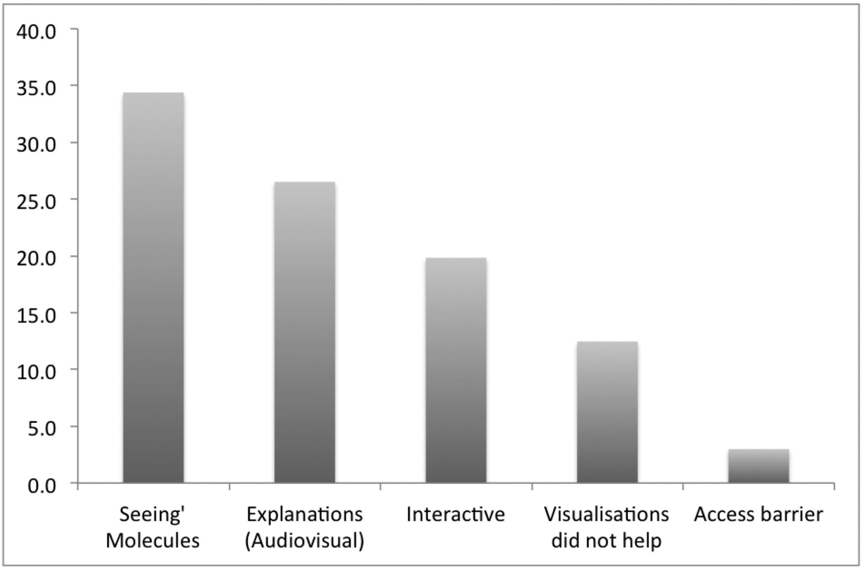

Figure 7. Percentage of responses to open response items on the student questionnaire coded into each theme.

Table 4 provides example quotes from student responses to the open ended items in regard to ChemBytes (each quote is chosen to be representative of at least 10 similar quotes). Many students referred to their preferred way of learning in terms of being a ‘visual’ learner or not and it was clear that a combination of modalities (multi-modal) is ideal with several students referring to the complementary nature of the combination of representations (Table 4).

During the process of designing the modules, audio explanations were not considered as a required element - it was hoped that students might be encouraged to explore the interactive elements rather than be directed by explanation. It was evident that a significant number of students preferred audio explanations of concepts through the videos or animations rather than the option of self-directed exploration (Table 4). This is consistent with research findings that narration combined with visualization reduces cognitive load (*54*).

Approximately 20% of responding students indicated that they enjoyed interactive visualizations such as PhET and Molecular Workbench. It was clear from their comments that the ability to decide on the variable (control) was a critical factor.

Table 4. Examples of typical student responses regarding the format of representation that was most useful in supporting their learning (online questionnaire)

Representational feature	***Example student perception***
'Seeing' molecular level phenomena	*From the videos and animation, we can see the molecules moving and reacting in a chemical reaction clearly which help me visualize the whole process*
Audio explanations	*The videos were most helpful because someone else was able to explain to me the processes that were occurring. A lot of the time, the animations and interactive visualizations did not explain what was going on, so were useless.*
Interactive exploration	*Interactive visualizations were the most helpful for me, because I was able to understand the concept more clearly due to the fact that I could control it and see the differences that occurred when I changed a particular aspect.*
Visual learner	*I think that the visualizations were always useful as I am more of a visual learner, and if I am able to see images of processes, I find that it becomes a lot clearer. Also, when I need to recall on these processes later on, I find that I can just think about the images in my head*
Non-visual learner	*I didn't find the visualizations useful, i prefer to learn through explinations [sic] rather than visually*
Focus on calculations	*none, the difficulty in the course is entirely based on the math, not visual concepts*
Multimodal	*All of them were somewhat useful by providing a unique way of learning chemistry. I don't consider one to be better than the other though (they complimented [sic] each other)*

One of the aims in the design of the modules was to incorporate elements that would appeal to the majority of students. However, 12% of those that responded indicated that they had not found the visualization activities useful. These students were divided in their reasons, which included:

- they were already familiar with concepts so did not feel they needed to access resources;
- they indicated that they were not visual learners and preferred to read text instead; and
- they preferred to learn through rehearsing or solving calculations.

The most troubling feedback was the group of students (3%) that claimed computer issues had prevented them from accessing various resources. They had not sought assistance that was widely available. This emergent issue of access and student technological skills was also apparent in focus group feedback, several students identified issues with their browsers and Java in particular, for example:

Schultz et al.; Technology and Assessment Strategies for Improving Student Learning in Chemistry
ACS Symposium Series; American Chemical Society: Washington, DC, 2016.

I use Safari a lot because I've got a Mac and I found that the activities didn't like being used with Safari. You had to use them Mozilla Firefox instead and because I'm always using Safari I'd have to close down Safari then log in on Mozilla, watch the activities and then do that and I'd have to do it every time because I'm always in Safari, that's just what I've got open, that's what it is (Focus Group 1)

It wanted you to download stuff onto your computer. And, like, my computer's a little bit touchy sometimes, like, there was one which I just didn't download because I was concerned it was going to have a virus in it or something because my computer started, like, flashing alarm things at me. Yeah, but I found the technical difficulties with the browsers and downloading stuff to be a bit frustrating. (Focus Group 2)

This finding is important in terms of widening student access to web-based learning modules. It is easy to assume that students have high levels of digital literacy. However, for our study it was clear that this was not the case and additional scaffolding or support is required to assist students to manage access through their own devices.

While we have no direct data from this study in regard to individual students' shifts in conceptual understanding through use of the online modules, the attitudes and perceptions described indicate that students mostly found these web-based modules to be useful. It can be inferred that students perceive usefulness through their continuance with the technology. The factor of post-usage usefulness is critical in determining continuance intention (*48*).

Conclusions

Five engaging online modules for addressing conceptual weaknesses of undergraduate students have been developed incorporating scaffolding, representations and feedback. Best practice in representations for chemistry was adopted to minimize potential cognitive load and enable visualization on the macroscopic and submicroscopic scales. This practice was informed by research (*36*) and the project team's own expertise (*45–47*, *58*). Two online web platforms were trialled to deliver these carefully designed modules and greater engagement of students was achieved in the open access website ChemBytes. Scaffolding and formative feedback have been incorporated into the modules to allow student monitoring of and reflection upon their progress.

Student adoption and continuance with the modules reflects the manner in which they have been integrated by teachers at their universities. Feedback in focus groups and surveys together with data showing high numbers of returning users suggest that students find the modules useful. The use of an open website or a single login with institutional credentials is critical to student engagement.

Acknowledgments

We thank all our student participants in focus groups and surveys and those who tested the websites. We thank the members of the project team Simon Bedford, Tim Dargaville, Glennys O'Brien, Roy Tasker and Chris Thompson for their creative input into module designs. We are also grateful to Marnie Holt, Trevor Daniels and Tanya Brady, who formed the technical team that developed the graphics and created the ChemBytes website. The ReSOLv website was created by one of the authorship team (Williams).

References

1. Xie, C.; Tinker, R.; Tinker, B.; Pallant, A.; Damelin, D.; Berenfeld, B. Computational experiments for science education. *Science* **2011**, *332*, 1516–1517, DOI: 10.1126/science.1197314.
2. The Concord Consortium. *Molecular Workbench*. http://mw.concord.org/modeler/ (accessed June 17, 2016).
3. PhET Interactive Simulations. *PhET*. https://phet.colorado.edu/(accessed June 17, 2016) . Creative Commons Attribution Licence (CC-BY) link: https://creativecommons.org/licenses/by/3.0/at/deed.en_GB.
4. Wieman, C. E.; Adams, W. K.; Perkins, K. K. PhET: Simulations that enhance learning. *Science* **2008**, *322*, 682–683, DOI: 10.1126/science.1161948.
5. Moore, E. B.; Herzog, T. A.; Perkins, K. K. Interactive simulations as implicit support for guided-inquiry. *Chem. Educ. Res. Pract.* **2013**, *14*, 257–268, DOI: 10.1039/C3RP20157K.
6. Khoshouie, E.; Ayub, A. F. M.; Mesrinejad, F. Molecular workbench software as computer assisted instruction to aid the learning of chemistry. *J. Educ. Soc. Res.* **2014**, *4*, 373–379, DOI: 10.5901/jesr.2014.v4n3p373.
7. Russell, J.; Kozma, R. B. Assessing learning from the use of multimedia chemical visualiztion software. In *Visualization in Science Education*; Gilbert, J. K., Ed.; Springer: Dordrecht, Netherlands, 2005; pp 299−332.
8. Feldman-Maggor, Y.; Rom, A.; Tuvi-Arad, I. Integration of open educational resources in undergraduate chemistry teaching – a mapping tool and lecturers' considerations. *Chem. Educ. Res. Pract.* **2016**, *17*, 283–295, DOI: 10.1039/c5rp00184f.
9. Rutten, N.; van Joolingen, W. R.; van der Veen, J. T. The learning effects of computer simulations in science education. *Comput. Educ.* **2012**, *58*, 136–153, DOI: 10.1016/j.compedu.2011.07.017.
10. Regan, Á.; Childs, P.; Hayes, S. The use of an intervention programme to improve undergraduate students' chemical knowledge and address their misconceptions. *Chem. Educ. Res. Pract.* **2011**, *12*, 219–227, DOI: 10.1039/C1RP90027G.
11. Treagust, D. F.; Chandrasegaran, A. L.; Zain, A. N. M.; Ong, E. T.; Karpudewan, M.; Halim, L. Evaluation of an intervention instructional program to facilitate understanding of basic particle concepts among students enrolled in several levels of study. *Chem. Educ. Res. Pract.* **2011**, *12*, 251–261, DOI: 10.1039/C1RP90030G.

12. Garnett, P.; Hackling, M. W.; Oliver, R. *Development of an interactive multimedia package designed to improve students' understanding of chemical equations*. Paper presented at 21st Annual Conference of the Western Australian Science Education Association, Perth, 1996.
13. Osborne, R. J.; Cosgrove, M. M. Children's conceptions of the changes of state of water. *J. Res. Sci. Teach.* **1983**, *20*, 825–838, DOI: 10.1002/tea.3660200905.
14. Mitchell, I.; Gunstone, R. Some student conceptions brought to the study of stoichiometry. *Res. Sci. Ed.* **1984**, *14*, 78–88, DOI: 10.1007/BF02356793.
15. Peterson, R. F.; Treagust, D. F.; Garnett, P. Development and application of a diagnostic instrument to evaluate grade 11 and 12 students' concepts of covalent bonding and structure following a course of instruction. *J. Res. Sci. Teach.* **1989**, *26*, 301–314, DOI: 10.1002/tea.3660260404.
16. Taber, K. S.; Tan, L. C. D. The insidious nature of 'hard core' alternative conceptions: Implications for the constructivist research programme of patterns in high school students' and pre-service teachers' thinking about ionisation energy. *Int. J. Sci. Ed.* **2011**, *33*, 259–297, DOI: 10.1080/09500691003709880.
17. Cooper, M.; Corley, L. M.; Underwood, S. M. An investigation of college chemistry students' understanding of structure–property relationships. *J. Res. Sci. Teach.* **2013**, *50*, 699–721, DOI: 10.1002/tea.21093.
18. Brandriet, A. R.; Bretz, S. L. The development of the Redox Concept Inventory as a measure of students' symbolic and particulate redox understandings and confidence. *J. Chem. Educ.* **2014**, *91*, 1132–1144, DOI: 10.1021/ed500051n.
19. Luxford, C. J.; Bretz, S. L. Development of the Bonding Representations Inventory to identify student misconceptions about covalent and ionic bonding representations. *J. Chem. Educ.* **2014**, *91*, 312–320, DOI: 10.1021/ed400700q.
20. Wren, D.; Barbera, J. Gathering evidence for validity during the design, development, and qualitative evaluation of thermochemistry concept inventory items. *J. Chem. Educ.* **2013**, *90*, 1590–1601, DOI: 10.1021/ed400384g.
21. Mulford, D. R.; Robinson, W. R. An inventory for alternate conceptions among first-semester general chemistry students. *J. Chem. Educ.* **2002**, *79*, 739–744, DOI: 10.1021/ed079p739.
22. Hand, B. M.; Treagust, D. F. Application of a conceptual conflict teaching strategy to enhance student learning of acids and bases. *Res. Sci. Ed.* **1988**, *18*, 53–63, DOI: 10.1007/BF02356580.
23. Li, S. C.; Law, N.; Liu, K. F. A. Cognitive perturbation through dynamic modelling: A pedagogical approach to conceptual change in science. *J. Comp. Assist. Learn.* **2006**, *22*, 405–422, DOI: 10.1111/j.1365-2729.2006.00187.x.
24. Limón, M. On the cognitive conflict as an instructional strategy for conceptual change: A critical appraisal. *Learn. Instr.* **2001**, *11*, 357–380, DOI: 10.1016/S0959-4752(00)00037-2.

25. Clark, D.; Jorde, D. Helping students revise disruptive experientially supported ideas about thermodynamics: Computer visualizations and tactile models. *J. Res. Sci. Teach.* **2004**, *41*, 1–23, DOI: 10.1002/tea.10097.
26. Kirbulut, Z. D.; Beeth, M. E. Consistency of students' ideas across evaporation, condensation, and boiling. *Res. Sci. Ed.* **2013**, *43*, 209–232, DOI: 10.1007/s11165-011-9264-z.
27. Nicol, D. Assessment for learner self-regulation: Enhancing achievement in the first year using learning technologies. *Assess. Eval. High. Ed.* **2009**, *34*, 334–352, DOI: 10.1080/02602930802255139.
28. Niroj, S.; Srisawasdi, N. *A blended Learning Environment in Chemistry for Promoting Conceptual Comprehension: A Journey to Target Students' Misconceptions.* Paper presented at 22nd International Conference on Computers in Education, Nara, Japan, 2014.
29. Wiggins, G. P.; McTighe, J. *Understanding by design*, 2nd ed.; Association for Supervision and Curriculum Development: Alexandra, VA, 2005.
30. Azevedo, R.; Hadwin, A. F. Scaffolding self-regulated learning and metacognition – implications for the design of computer-based scaffolds. *Instr. Sci.* **2005**, *33*, 367–379, DOI: 10.1007/s11251-005-1272-9.
31. Means, B.; Toyama, Y.; Murphy, R.; Bakia, M.; Jones, K. *Evaluation of Evidence-Based Practices in Online Learning: A Meta-Analysis and Review of Online Learning Studies*; U.S. Department of Education, Office of Planning, Evaluation, and Policy Development, 2009.
32. Pea, R. D. The social and technological dimensions of scaffolding and related theoretical concepts for learning, education, and human activity. *J. Learn. Sci.* **2004**, *13*, 423–451, DOI: 10.1207/s15327809jls1303_6.
33. Chiu, M.-H.; Wu, H.-K. The roles of multimedia in the teaching and learning of the triplet relationship in chemistry. In *Multiple representations in chemical education*; Gilbert, J. K., Treagust, D. F., Eds.; Springer: Dordrecht, Netherlands, 2009, pp 251-283.
34. Nicol, D. J.; MacFarlane-Dick, D. Formative assessment and self-regulated learning: A model and seven principles of good feedback practice. *Stud. High. Educ.* **2006**, *31*, 199–218, DOI: 10.1080/03075070600572090.
35. Mayer, R. E. Cognitive theory and the design of multimedia instruction: An example of the two-way street between cognition and instruction. *New Directions Teach. Learn.* **2002**, 55–71, DOI: 10.1002/tl.47.
36. Mayer, R. E.; Moreno, R. Nine ways to reduce cognitive load in multimedia learning. *Ed. Psych.* **2003**, *38*, 43–52, DOI: 10.1207/S15326985EP3801_6.
37. Belland, B. R. Scaffolding: Definition, current debates, and future directions. In *Handbook of Research on Educational Communications and Technology*, 4th ed.; Spector, M. J., Merrill, M. D., Elen, J., Bishop, M. J., Eds.; Springer: New York, 2014; pp 505−518.
38. Puntambekar, S.; Kolodner, J. L. Toward implementing distributed scaffolding: Helping students learn science from design. *J. Res. Sc. Teach.* **2005**, *42*, 185–217, DOI: 10.1002/tea.20048.
39. Tabak, I. Synergy: A complement to emerging patterns of distributed scaffolding. *J. Learn. Sc.* **2004**, *13*, 305–335, DOI: 10.1207/s15327809jls1303_3.

40. Quintana, C.; Zhang, M.; Krajcik, J. A framework for supporting metacognitive aspects of online inquiry through software-based scaffolding. *Ed. Psych.* **2005**, *40*, 235–244, DOI: 10.1207/s15326985ep4004_5.
41. Quintana, C.; Reiser, B. J.; Davis, E. A.; Krajcik, J.; Fretz, E.; Duncan, R. G.; Kyza, E.; Edelson, D.; Soloway, E. A scaffolding design framework for software to support science inquiry. *J. Learn. Sci.* **2004**, *13*, 337–386, DOI: 10.1207/s15327809jls1303_4.
42. McRae, C.; Karuso, P.; Liu, F. Chemvoyage: A web-based, simulated learning environment with scaffolding and linking visualization to conceptualization. *J. Chem. Educ.* **2012**, *89*, 878–883, DOI: 0.1021/ed200533u.
43. Al-Balushi, S. M.; Al-Hajri, S. H. Associating animations with concrete models to enhance students' comprehension of different visual representations in organic chemistry. *Chem. Educ. Res. Pract.* **2014**, *15*, 47–58, DOI: 10.1039/c3rp00074e.
44. Johnstone, A. H. Why is science difficult to learn? Things are seldom what they seem. *J. Comp. Assist. Learn.* **1991**, *7*, 75–83, DOI: 10.1111/j.1365-2729.1991.tb00230.x.
45. Tasker, R. Visualising the molecular world for a deep understanding of chemistry. *Teach. Sci.* **2014**, *60*, 16–27.
46. Tasker, R. *Vischem.* http://www.vischem.com.au (accessed August 31, 2016).
47. Tasker, R.; Dalton, R. Research into practice: Visualisation of the molecular world using animations. *Chem. Educ. Res. Pract.* **2006**, *7*, 141–159, DOI: 10.1039/B5RP90020D.
48. Bhattacherjee, A.; Perols, J.; Sanford, C. Information technology continuance: A theoretic extension and empirical test. *J. Comput. Inform. Syst.* **2008**, *49*, 17–26, DOI: 10.1080/08874417.2008.11645302.
49. Lawrie, G.; Wright, A.; Schultz, M.; Dargaville, T.; O'Brien, G.; Bedford, S.; Williams, M.; Tasker, R.; Dickson, H.; Thompson, C. Using formative feedback to identify and support first year chemistry students with missing or misconceptions. A practice report. *Int. J. First Year High. Ed.* **2013**, *4*, 111−116. DOI: 10.5204/intjfyhe.v4i2.179. Creative Commons Attribution Licence (CC-BY) link: https://creativecommons.org/licenses/by/3.0/at/deed.en_GB.
50. Schultz, M.; Lawrie, G. A.; Bailey, C. H.; Bedford, S. B.; Dargaville, T. R.; O'Brien, G.; Tasker, R.; Thompson, C. D.; Williams, M.; Wright, A. H. Evaluation of diagnostic tools that tertiary teachers can apply to profile their students' conceptions. *Int. J. Sci. Ed.*submitted.
51. Briggs, D. C.; Alonzo, A. C. *The Psychometric Modeling of Ordered Multiple-Choice Item Responses for Diagnostic Assessment with a Learning Progression.* Paper presented at Learning Progressions in Science, Iowa City, IA, 2009.
52. Hadenfeldt, J. C.; Bernholt, S.; Liu, X.; Neumann, K.; Parchmann, I. Using ordered multiple-choice items to assess students' understanding of the structure and composition of matter. *J. Chem. Educ.* **2013**, *90*, 1602–1608, DOI: 10.1021/ed3006192.

53. Ainsworth, S.; Newton, L. Teaching and researching visual representations: Shared vision or divided worlds? In *Science Teachers' Use of Visual Representations*; Eilam, B., Gilbert, J. K., Eds.; Springer: Cham, Switzerland, 2014; pp 29−49.
54. Mousavi, S. Y.; Low, R.; Sweller, J. Reducing cognitive load by mixing auditory and visual presentation modes. *J. Ed. Psych.* **1995**, *87*, 319–334, DOI: 10.1037/0022-0663.87.2.319.
55. McIntyre, R.; Wegener, M.; McGrath, D. *Five Minute Physics*. http://teaching.smp.uq.edu.au/fiveminutephysics/ (accessed June 17, 2016).
56. Wegener, M.; McIntyre, T.; McGrath, D.; Talbot, C. *Concise, Interactive e-Learning Modules for Student Lecture Preparation*. Paper presented at The Australian Conference on Science and Mathematics Education, Canberra, Australia, 2013.
57. Phillips, R.; McNaught, C.; Kennedy, G. *Evaluating e-learning: Guiding research and Practice*; Routledge: New York, 2012.
58. Tasker, R. ConfChem conference on interactive visualizations for chemistry teaching and Learning: Research into practice - Visualizing the molecular world for a deep understanding of chemistry. *J. Chem. Educ.* **2016**, *93*, 1152–3, DOI: 10.1021/acs.jchemed.5b00824.